A GENERALIZED FINITE-DIFFERENCE FORMULATION FOR THE

U.S. GEOLOGICAL SURVEY MODULAR THREE-DIMENSIONAL

FINITE-DIFFERENCE GROUND-WATER FLOW MODEL

U.S. Geological Survey

Open-File Report 91-494

USGS

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Report Documentation Page

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1. REPORT DATE **1992**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **A Generalized Finite-Difference Formulation for the U.S. Geological Survey Modular Three-Dimensional Finite-Difference Ground-Water Flow Model**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Department of the Interior 1849 C Street, NW Washington, DC 20240**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**

13. SUPPLEMENTARY NOTES
14. ABSTRACT
15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**60**	

A GENERALIZED FINITE-DIFFERENCE FORMULATION FOR THE U.S. GEOLOGICAL SURVEY MODULAR THREE-DIMENSIONAL FINITE-DIFFERENCE GROUND-WATER FLOW MODEL

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A GENERALIZED FINITE-DIFFERENCE FORMULATION FOR THE U.S. GEOLOGICAL SURVEY MODULAR THREE-DIMENSIONAL FINITE-DIFFERENCE GROUND-WATER FLOW MODEL

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ABSTRACT

The U.S. Geological Survey's Modular Ground-Water Flow Model assumes that model nodes are in the center of cells and that transmissivity is constant within a cell. Based on these assumptions, the model calculates coefficients, called conductance, that are multiplied by head difference to determine flow between cells. Although these are common assumptions in finite-difference models, other assumptions are possible. A new option to the model program reads conductance as input data rather than calculating it. This option allows the user to calculate conductance outside of the model. The user thus has the flexibility to define conductance using any desired assumptions.

For a water-table condition, horizontal conductance must change as water level varies. To handle this situation, the new option reads conductance divided by thickness (CDT) as input data. The model calculates saturated thickness and multiplies it by CDT to obtain conductance. Thus, the user is still free from the assumptions of centered nodes and constant transmissivity in cells.

The model option is written in FORTRAN 77 and is fully compatible with the existing model. This report documents the new model option; it includes a description of the concepts, detailed input instructions, and a listing of the code.

INTRODUCTION

The U.S. Geological Survey developed a modular ground-water flow simulation program that uses the finite-difference approximation (McDonald and Harbaugh, 1988). Although the model can simulate a variety of problems, it also was designed so that new capabilities could be easily added if needed. This report describes a new option to the program that removes some of the assumptions that were made for the calculation of flow between model nodes.

The modular structure of the model makes it easy to modify (McDonald and Harbaugh, 1988, p. 1-2). Each module is small and compact, and the modules are grouped, mainly by hydrologic function, into packages. Modules dealing with internal aquifer flow, which is flow between cells and flow into storage, are grouped into a package, herein called the internal flow package. There can be only one internal flow package in use at a time, and in fact there is only one such package in the original model, the Block-Centered Flow (BCF) Package.

To implement the new option described in this report, a second internal flow package was developed. The new package is called the General Finite-Difference Flow (GFD) Package. The structure of the GFD Package is consistent with that of the original model and is written in the FORTRAN 77 programming language (ANSI, 1978) as is the original model. The BCF Package was left in the model so that it may still be used when desired. All other model packages are unaffected by the new GFD Package.

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The remainder of this report describes how the GFD Package is implemented and how to use it; however, it is not the purpose of this report to describe when to use the new package. Readers should use hydrologic judgement to decide what assumptions are best for their applications. This report is intended to be used as a supplement to the documentation of the model by McDonald and Harbaugh (1988).

The finite-difference flow equation for a model node (i,j,k), where i, j, and k are row, column, and layer grid indexes respectively, is (McDonald and Harbaugh, 1988, p. 2-26):

$$CV_{i,j,k-1/2}h^m_{i,j,k-1} + CC_{i-\frac{1}{2},j,k}h^m_{i-1,j,k} + CR_{i,j-\frac{1}{2},k}h^m_{i,j-1,k}$$

$$+ \left(- CV_{i,j,k-\frac{1}{2}} - CC_{i-\frac{1}{2},j,k} - CR_{i,j-\frac{1}{2},k} - CR_{i,j+\frac{1}{2},k} - CC_{i+\frac{1}{2},j,k} - CV_{i,j,k+\frac{1}{2}} + HCOF_{i,j,k}\right)h^m_{i,j,k}$$

$$+ CR_{i,j+\frac{1}{2},k}h^m_{i,j+1,k} + CC_{i+\frac{1}{2},j,k}h^m_{i+1,j,k} + CV_{i,j,k+\frac{1}{2}}h^m_{i,j,k+1} = RHS_{i,j,k} \qquad (1)$$

Equation 1 is written for each time step in a simulation, and the m superscript designates the time step number. Hydraulic head is designated by h. The HCOF and RHS terms incorporate storage and external stresses. The CR, CC, and CV terms are conductances. Conductance is the product of hydraulic conductivity and cross-sectional area of flow divided by the length of the flow path and results from application of Darcy's law describing one-dimensional, steady-state flow occurring in a volume of porous material. Darcy's law says that flow through a volume of porous material is the product of conductance and the head difference along the flow path. The terms in equation 1 involving conductance specify the flow between the node for which the equation is being written and its six neighboring nodes.

Conductance of a volume of porous material is defined as (fig. 1)

$$C = KWb/L \qquad (2)$$

where

> K is hydraulic conductivity in the direction of flow,
> W is the width of the volume in one direction perpendicular to flow,
> b is the width of the volume in the other direction perpendicular to flow, and
> L is the length of the volume in the direction of flow.

Note that the direction of flow plays an important part in the definition of conductance. The conductance for a volume of material may vary significantly for different directions of flow.

Each conductance in equation 1 represents the properties of flow of the material between two nodes. That is, model conductance does not apply to a single cell. Subscript indexes for conductance values contain + or -1/2 to indicate the area represented by the conductance. For example, CC(i-1/2,j,k) represents conductance between nodes (i-1,j,k) and (i,j,k). Similarly, CR(i,j+1/2,k) is the conductance between nodes (i,j,k) and (i,j+1,k). Figure 2 shows two model cells, (i,j,k) and (i,j+1,k), and the volume of porous material represented by conductance CR(i,j+1/2,k). Similar diagrams could be drawn to illustrate model conductance between cell (i,j,k) and the other five adjacent cells.

$$C = \frac{KWb}{L} \quad \text{where K is hydraulic conductivity.}$$
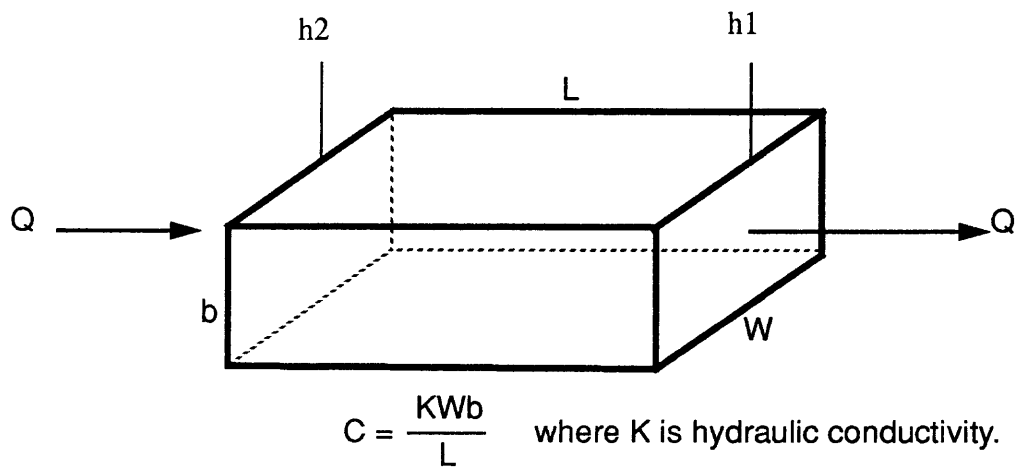
Darcy's Law: $Q = C(h2 - h1)$ where Q is the flow through the block and
h2 and h1 are heads at the ends of the block.

Figure 1. -- Definition of conductance (C) for a volume of porous material.

Perspective View
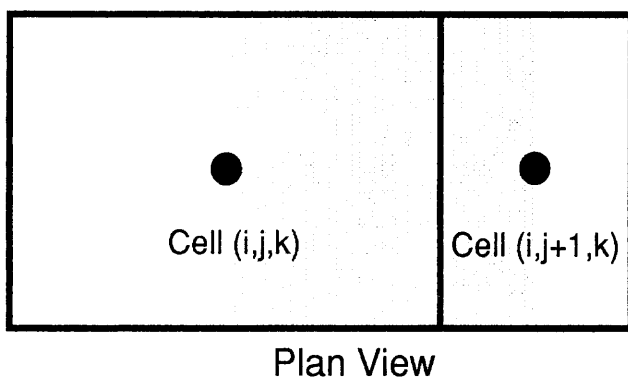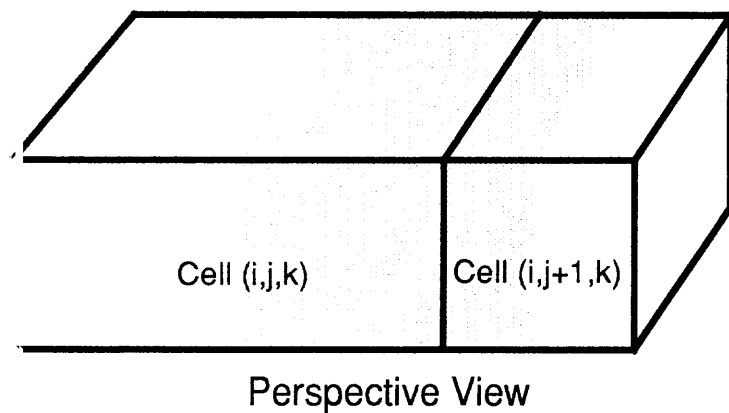
Explanation

● Node within cell.

Volume of material
represented by conductance
$CR(i,j+1/2,k)$.

Plan View

Figure 2. -- Conductance between two model nodes.

The BCF Package calculates horizontal conductance from the hydraulic conductivity and cell dimensions specified for individual cells. In order to develop the equations for calculating conductances, it is assumed that model nodes are located at the center of cells, called a block-centered grid, and that transmissivity is constant within a cell (McDonald and Harbaugh, 1988, p. 5-6). Although transmissivity is assumed to be constant within a cell, it may vary from cell to cell, which results in discrete changes in transmissivity at cell boundaries.

The assumptions of a block-centered grid and constant transmissivity within a cell are not required for the development of equation 1, and the GFD Package removes these assumptions. The goal for this new option was to allow the user full freedom to specify conductances as desired. For confined cells this goal is easily met; conductance is simply read as input data. Thus the user now can calculate conductance externally using any desired assumptions. For unconfined cells, however, this goal is only partly achievable.

For unconfined cells, conductance cannot be read as input because it must change during the simulation according to changes in calculated water level. The GFD Package calculates saturated thickness and reads as input conductance divided by thickness between nodes. The program then calculates conductance as the product of saturated thickness and conductance divided by thickness. Conductance divided by thickness represents material between nodes and can be calculated in any way the user prefers, which is less restrictive than the original model.

The GFD Package can be useful in many situations, a few of which are briefly mentioned here.

1. A point-centered grid in which cell boundaries are equally spaced between nodes (McDonald and Harbaugh, 1988, p. 2-5) is sometimes desired instead of a block-centered grid.

2. The radial-flow finite-difference equation has the same form as equation 1 (Stallman, 1963). Thus, a radial flow model can be constructed using the GFD Package if the conductances are calculated using radial geometry.

3. When changes in transmissivity between nodes are large, conductance values can vary significantly depending on the assumptions regarding the distribution of transmissivity. Appel (1976) derives a formula for calculating interblock transmissivity when transmissivity varies linearly between model nodes.

4. The geometry of an aquifer can sometimes be more accurately represented using the GFD Package. In the BCF Package, changing the transmissivity for one cell affects the conductances to all four neighboring horizontal cells. With the GFD Package, any individual conductance to a cell can be adjusted without impacting the other conductances to that cell. As an example, this can be useful for simulating a flow barrier; those conductances that are affected by the barrier can be adjusted without affecting other nearby conductances.

5. Finally, horizontal anisotropy must be constant for an entire layer in the BCF Package, but the GFD Package can be used to specify anisotropy variations cell by cell. Note that the principal axes of hydraulic conductivity must be aligned with the model grid, which is an assumption inherent in the partial-differential flow equation on which the model is based (McDonald and Harbaugh, 1988, p. 2-1).

IMPLEMENTATION OF THE GENERAL FINITE-DIFFERENCE FLOW PACKAGE

The model formulates equation 1 at each model node. An internal flow package calculates the six conductances (CR, CC, and CV) used in equation 1. Storage terms, which are incorporated in RHS and HCOF terms, are also calculated by an internal flow package.

Conductance

Horizontal Conductance for Confined Model Layers

For confined model cells, the horizontal conductances (CR and CC) are read as input data, and therefore the user must calculate the conductance values prior to making a simulation. These conductances remain constant throughout the simulation.

Equation 2 is used to calculate conductance for a rectangular grid. When calculating horizontal conductance between two nodes in a row with a rectangular grid, W is the width of the row, b is the thickness of the model layer between the two nodes, L is the horizontal distance between the two nodes, and K is the horizontal hydraulic conductivity between the nodes. When calculating horizontal conductance between two nodes in a column of a rectangular grid, W is the width of the column, b is the thickness of the model layer between the two nodes, L is the horizontal distance between the two nodes, and K is the hydraulic conductivity between the nodes.

Horizontal Conductance for Unconfined and Convertible Model Layers

In an unconfined aquifer, horizontal conductance changes as the saturated thickness of the aquifer changes. Thus, horizontal conductance values must be calculated within the model during the simulation rather than being specified as constants, as in the confined situation. In the GFD Package, this is accomplished by having the user supply values of conductance divided by thickness (CDT) between nodes. CDT is obtained by dividing equation 2 by thickness b:

$$CDT = KW/L. \tag{3}$$

CDT values are read as input and represent the aquifer material between nodes just as conductance values do. Given a uniform saturated thickness within a volume of porous material, conductance is simply the product of CDT and saturated thickness. Saturated thickness at nodes is calculated within the GFD Package during the simulation just as it is done within the BCF Package (McDonald and Harbaugh, 1988, p. 5-9):

h-BOT	for	TOP > h > BOT,	(4a)
TOP-BOT	for	h ≥ TOP, or	(4b)
0	for	h ≤ BOT,	(4c)

where

> h is the current head at node (i,j,k),
> BOT is the elevation of the aquifer bottom at node (i,j,k), and
> TOP is the elevation of the aquifer top at node (i,j,k).

Saturated thickness is generally not uniform between nodes, so a formulation for calculating horizontal conductance from CDT between nodes and saturated thickness at nodes must be developed. The approach used for the GFD Package is to calculate an equivalent saturated thickness that, when multiplied by CDT and head difference, results in the correct flow.

Appel (1976) shows that an equivalent transmissivity, T, for one-dimensional flow in a rectangular volume of porous material in which transmissivity varies linearly along the flow path is

$$T = (T2 - T1)/\ln(T2/T1) \tag{5}$$

where

   T2 is transmissivity at one end of the volume and
   T1 is transmissivity at the other end of the volume.

In order to implement a form of equation 5 in the GFD Package, it is assumed that hydraulic conductivity is uniform between nodes and that the saturated thickness varies linearly between nodes. The product of a constant hydraulic conductivity and a linearly varying saturated thickness will produce a linearly varying transmissivity, which is the assumption on which equation 5 is based. Clearly, a linear variation of saturated thickness between nodes is only an approximation because of the water-table curvature and the typical aquifer bottom irregularities. However, it is generally possible to make cells small enough (through specification of the horizontal grid spacing) so that such an approximation is reasonable.

If saturated thickness times a constant hydraulic conductivity is substituted for transmissivity in equation (5), hydraulic conductivity cancels, and the result is

$$B = (B2 - B1)/\ln(B2/B1) \tag{6}$$

where

   B is equivalent saturated thickness for the volume,
   B2 is saturated thickness at one end of the volume, and
   B1 is saturated thickness at the other end of the volume.

Although equation 6 provides a workable formulation of equivalent saturated thickness, computational efficiency of the conductance calculations is also important in the model program when there is a large number of unconfined cells. Logarithm calculation is computationally intensive, and an alternative is desirable. Appel (1976) shows that when T1 and T2 are nearly equal, the average of T1 and T2 is a good approximation of T in equation 5. It follows that

$$Bavg = (B1 + B2)/2, \tag{7}$$

is a good approximation of B in equation 6 when B1 and B2 are nearly equal. In particular, Bavg is within 0.5 percent of B whenever B2/B1 is less than 1.25 and greater than 0.8. Therefore, in the GFD Package, Bavg is used as equivalent saturated thickness when B2/B1 is less than 1.25 and greater than 0.8. Otherwise, B as defined in equation 6 is used.

The GFD Package calculates conductance for unconfined layers, and layers that can convert between confined and unconfined at the beginning of each iteration using the head from the previous iteration to calculate saturated thickness. If either cell in this calculation has 0 saturated

thickness, then the conductance is defined as 0 and the cell becomes inactive (is converted to no flow). This means that all 4 horizontal conductances to a cell will be 0 whenever saturated thickness at the cell is 0. In addition, the two vertical conductances connecting to a cell with 0 saturated thickness are set to 0. A cell cannot be changed from inactive to active.

One further note on the applicability of the water-table conductance calculation is that Appel's (1976) formulation for transmissivity was developed for a rectangular volume assuming one-dimensional steady-state flow. Under the assumptions of a water table and a non-flat bottom, the volume being simulated by the GFD Package will not be rectangular and flow will not be one dimensional. Yet, the assumptions are reasonable approximations in many situations. In particular, the assumptions are valid when the aquifer bottom variations and water-table curvature are small compared to the horizontal grid spacing. These assumptions are similar to, and no more restrictive than, the assumptions made in the BCF Package for calculating conductance for unconfined cells; further, there is no need to make an assumption about node location within a cell as in the BCF Package. Thus the goal of making the GFD Package independent of node orientation is maintained.

The model user must calculate CDT values outside of the model. Use equation 3 to calculate CDT values for a rectangular grid. When calculating CDT between two nodes in a row in a rectangular grid, W is the width of the row, L is the horizontal distance between the two nodes, and K is the hydraulic conductivity between the nodes. When calculating CDT between two nodes in a column of a rectangular grid, W is the width of the column, L is the horizontal distance between the two nodes, and K is the hydraulic conductivity between the nodes.

Vertical Conductance

Values of vertical conductance between cells (CV) are read as input in all situations, whether the connected nodes are specified as confined or unconfined. (Note that the BCF Package reads as input vertical conductance divided by cell area [McDonald and Harbaugh, 1988, p. 5-12]). In unconfined conditions, vertical conductance does not change with saturated thickness; except that if a node becomes inactive, then both vertical conductances connecting to neighboring nodes are set to 0. Use equation 2 to calculate vertical conductance values for a rectangular grid. In this situation, W and b are the horizontal dimensions (input parameters DELR and DELC) of the two cells containing the nodes between which conductance is being calculated, L is the vertical distance between the two nodes, and K is the hydraulic conductivity between the nodes.

Vertical Flow Calculation Under Dewatered Conditions

When a cell below another cell becomes unconfined, there is an unsaturated zone between them. Flow through the unsaturated zone is no longer dependent on the head in the lower cell. Vertical flow is a function of the difference between the head in the upper cell and the elevation of the top of the lower cell. This situation causes a change in the basic finite-difference equation 1, which is handled as described by McDonald and Harbaugh (1988, p. 5-19). Compensating terms for the erroneous head difference are added to RHS and HCOF coefficients.

Storage Terms

Storage terms are added to the flow equation exactly as described by McDonald and Harbaugh (1988, p. 5-24) for the BCF Package. A summary of these terms follows.

For the case of a model cell that is either strictly confined or strictly unconfined, the expression for the rate of accumulation, Q, of water in a cell as a result of storage is

$$Q = SC1(h - HOLD)/DELT, \tag{8}$$

where

> SC1 is storage capacity (product of cell area and specific yield or confined storage coefficient),
> HOLD is the head at the start of the time step,
> h is the head at the end of the time step, and
> DELT is the length of the time step.

In the formulation of equation (1), the term -SC1/DELT is added to HCOF and -SC1*HOLD/DELT is added to RHS.

In the case of a cell that is converting between confined and unconfined and vice versa during a time step, the expression for the rate of accumulation, Q, of water in a cell as a result of storage is

$$Q = [SCB(h-TOP) + SCA(TOP-HOLD)] / DELT \tag{9}$$

where

> TOP is the elevation of the top of the aquifer in the cell,
> SCA is storage capacity in effect at the start of the time step, and
> SCB is the storage capacity in effect at the current iteration.

The term -SCB/DELT is added to HCOF and term (-SCB(TOP)+SCA(TOP-HOLD))/DELT is added to RHS in equation 1.

Storage capacity is required for the storage calculations as indicated by equations 8 and 9. To be consistent with the goal of being independent of the geometry of cells, storage capacity is directly read as input in the GFD Package. This is different than in the BCF Package, where storage coefficient or specific yield are read as input, and the package multiples these by cell area to obtain storage capacity.

APPLICABILITY AND LIMITATIONS OF OPTIONAL FORMULATIONS

The optional formulations for water-table conductance, vertical leakage correction, and confined/ unconfined storage conversion were developed using the conceptualization of a layered aquifer system in which each aquifer is simulated by one model layer and the aquifer layers are separated by distinct confining units. Using these options where these conditions are not satisfied may lead to problems and inaccuracies. For example, vertical conductance is left constant until a cell converts to no flow, and then it is set to zero. For this to be reasonable, there must generally be a confining layer, which is the dominant factor in controlling vertical flow, below the model water-table layer. These limitations are similar to the limitations for the BCF Package (McDonald and Harbaugh, 1988, p. 5-30).

DATA REQUIREMENTS

The fundamental parameters controlling cell-to-cell flow and storage are read by the General Finite-Difference Package as input data. These parameters may include conductance, conductance divided by saturated thickness (CDT), storage capacity, aquifer bottom elevation, and aquifer top elevation. The specific parameters that are read depend on which options are invoked.

The GFD Package is required to define the grid spacing even though the GFD Package does not require cell dimensions in order to calculate conductance, storage capacity, or any other parameter. Although the grid dimensions are already incorporated into the input parameters used by the GFD Package, an internal flow package is required to define grid spacing so that it can be used by other packages. Other packages, for example the recharge package, that use values of grid spacing use them only to calculate cell area. No assumptions about the location of nodes within cells are implied by specifying grid spacing. The grid spacing indicates the length of cells along rows (DELR) and columns (DELC). Cell area is calculated as the product of DELR and DELC for that cell. If non-rectangular cells are being used, such as would be the case for a radial flow model, then values for DELR and DELC must be specified so that their product results in the correct cell area.

The user specifies a "layer-type code" for each layer. All cells in a layer have the same type code. The layer-type code indicates the options in effect for the cells in a layer, and thus the data requirements for a layer. Data for a layer are input as a series of two-dimensional arrays, one array for each required parameter. All the required arrays are read for a given layer before reading any data for the next layer. That is, all required arrays are read for layer 1, then layer 2 arrays are read, and so on until data has been read for all layers.

The required parameters should be specified for every cell of a layer, including constant-head and no-flow cells. For no-flow cells, the entered values are never used in calculations; therefore, any values may be specified. For constant-head cells, the storage capacity values are not used, but the other parameters are. Realistic values must be specified at constant-head cells for all parameters except storage capacity.

For each node (i,j,k), three conductance values, or two conductance divided by thickness (CDT) values and one vertical conductance value, are read as input data. As with all layer data, conductance and CDT are read as two-dimensional arrays. The names of the conductance arrays correspond to the names of variables in equation (1), which are CR, CC, and CV. The two CDT arrays are named CDTR and CDTC. Conductances and CDT values are indexed according to node indexes even though they represent material between nodes. The conductance between node (i,j,k) and node $(i,j+1,k)$ is read as $CR(i,j,k)$; the conductance between node (i,j,k) and node $(i+1,j,k)$ is read as $CC(i,j,k)$. Likewise, the conductance between node (i,j,k) and node $(i,j,k+1)$ is read as $CV(i,j,k)$. There are three other conductances connected to node (i,j,k), but these are associated with neighboring nodes. For example, the conductance between node (i,j,k) and node $(i,j-1,k)$ is $CC(i,j-1,k)$. CDTR and CDTC values are indexed the same as CR and CC respectively. $CDTR(i,j,k)$ is CDT between nodes (i,j,k) and $(i,j+1,k)$; $CDTC(i,j,k)$ is CDT between nodes (i,j,k) and $(i+1,j,k)$.

Although conductance and CDT values are indexed according to node location, it is important to remember that the values represent the material between nodes. There is no need for vertical conductance values for the bottom layer because the vertical conductance assigned to the nodes in

the bottom layer represents conductance between the nodes in that layer and a nonexistent layer below. Accordingly, the vertical conductance for the bottom layer is not read; CV for the bottom layer must not be included in the input data. For each layer, either CR or CDTR must be read; however, the values for the last column are not used. That is, values for nodes (i,NCOL,k), in which NCOL is the maximum column number, are not used. This is because these values represent conductance between nodes in the last column and the next column, which does not exist because it is outside of the model. Although values must be specified for the last column, the values for the last column are ignored. Similarly for CC and CDTC, the values for the last row, that is for nodes (NROW,j,k) in which NROW is the maximum row number, must be included as part of the input array; however, these values are ignored because they represent conductance to nodes that are outside of the model. A no-flow boundary is automatically imposed around the entire model perimeter.

Storage capacity is not needed for steady-state simulations. A flag (ISS) has been provided to allow the user to specify that a simulation is steady state. When ISS is nonzero, space for storage capacity is not allocated, storage capacity is not read, and storage calculations are skipped.

Four values for the layer-type code are accepted by the GFD Package. These values identify which of the various combinations of the options provided by the package are to be used for a layer. The layer-type codes are stored in the one-dimensional array LAYCON. The code values and the corresponding options invoked are given below. The layer-type code is identical in meaning to the layer-type code in the BCF Package.

Layer-type code 0 indicates that horizontal conductance and storage capacity are constant. There is no provision for adjusting conductance, limiting vertical flow from above, or adjusting storage terms as water level varies. This layer type is usually used to simulate confined conditions. This option could also be used to simulate unconfined conditions provided that simulated water-level changes are a small fraction of saturated thickness and flow from an overlying layer (if present) can be assumed to be negligible.

Input required for each node in the layer:

SC1 -- Confined or unconfined storage capacity (only for transient simulations),

CR -- Conductance between each node and the next adjacent node along a row,

CC -- Conductance between each node and the next adjacent node along a column, and

CV -- Conductance between each node in the layer and each node in the layer below (only if there is a layer below).

Layer-type code 1 indicates a strictly unconfined layer, and can be used only for the top layer of a model. Horizontal conductance is calculated each iteration as the product of saturated thickness and conductance divided by saturated thickness; however, there is no upper limit on saturated thickness, and there is no provision for storage term conversion. Also, there is never any limitation on vertical flow from layers above because this layer type is valid only for the top layer.

Input required for each node in the layer:

SC1   --   Unconfined storage capacity (only for transient simulations),

CDTR --   Conductance divided by thickness between each node and the next adjacent node along a row,

CDTC --   Conductance divided by thickness between each node and the next adjacent node along a column,

BOT   --   Elevation of the bottom of the aquifer, and

CV   --   Conductance between each node in the layer and each node in the layer below (only if there is a layer below).

Layer-type code 2 indicates a layer that may alternate between confined and unconfined, but conductance is held constant throughout the simulation. This is useful in situations where storage term conversion and limitation of flow from above under dewatered conditions are desirable, and yet saturated thickness changes are small compared to the saturated thickness so that recalculation of conductance as a function of saturated thickness changes is not necessary.

Input required for each node in the layer.

SC1   --   Storage capacity to be used when nodes are confined (only for transient simulations),

CR   --   Conductance between each node and the next adjacent node along a row,

CC   --   Conductance between each node and the next adjacent node along a column,

SC2   --   Storage capacity to be used when nodes are unconfined (only for transient simulations),

TOP   --   Elevation of the top of the aquifer, and

CV   --   Conductance between each node in the layer and each node in the layer below (only if there is a layer below).

Layer-type code 3 indicates a layer that may alternate between confined and unconfined, and all of the options associated with water-table conditions are incorporated. Conductance is calculated each iteration as the product of saturated thickness and conductance divided by saturated thickness. Storage terms can convert back and forth between confined and unconfined, and vertical flow from above is limited at nodes that are unconfined.

Input required for each node in the layer:

SC1   --   Storage capacity to be used when nodes are confined (only for transient simulations),

CDTR --   Conductance divided by thickness between each node and the next adjacent node along a row,

CDTC --   Conductance divided by thickness between each node and the next adjacent node along a column,

BOT   --   Elevation of the bottom of the aquifer,

SC2   --   Storage capacity to be used when nodes are unconfined (only for transient simulations),

TOP   --   Elevation of the top of the aquifer, and

CV -- Conductance between each node in the layer and each node in the layer below (only if there is a layer below).

Only the required arrays as indicated by the LAYCON value for each layer are read. Care must be taken to ensure that only the required data is included in the input data. Otherwise, the data will be incorrectly read by the program.

The four layer-type designations allow the user to control the complexity of the formulations. Layer-type codes 1-3 result in greater usage of computer memory and execution time than does layer-type code 0. Layer-type code 3 uses the most memory and execution time. Also, layer-type codes 1-3 can cause numerical instability that can prevent the iterative solvers from converging to a solution, and therefore, layer-type codes 1-3 should be used only when necessary.

INPUT INSTRUCTIONS

The input to the General Finite-Difference Flow (GFD) Package is listed by "items" of input. An item defines one or more input parameters, and each item requires one or more input records. An input parameter may be an individual value, or it may be an array having multiple values. Each item is numbered. The description of an item contains a line that names the parameters and a line showing the format of the parameters. For parameters that are individual values and some of the parameters that are arrays, the format is given in standard FORTRAN notation. The format for the remainder of the arrays is defined by naming the utility module that reads them. Details about the array reading utility modules are contained in McDonald and Harbaugh (1988, p. 14-4). Following the list of items is a list of definitions of input parameters. The variables and arrays used in the program have the same names as the parameters they represent.

Input for the GFD Package is read from the unit specified in IUNIT(14). IUNIT is an array of file unit numbers that is read by the Basic Package. A positive number for IUNIT(14) indicates that GFD is to be used, and that number is the unit number on which the input data are to be read. See McDonald and Harbaugh (1988, p. 3-25) for an explanation of the IUNIT array. Note that a different element within IUNIT may be used if IUNIT(14) is already being used by another package. (See Module Documentation section.) When executing the model, either the GFD or the BCF Package must be used. IUNIT(1) is the input unit number for the BCF Package. Thus, either IUNIT(1) or IUNIT(14) must be positive, but not both. The data are read once at the start of a simulation.

Module GFD1AL reads items 1-2:

1. Data: ISS   IGFDCB
    Format: I10   I10

2. Data: LAYCON(NLAY)   (Maximum of 80 layers)
    Format: 40I2

    (If there are 40 or fewer layers, use one record; otherwise, use two records.)

Module GFD1RP reads items 3-13:

3. Data: DELR(NCOL)
    Module: U1DREL

4. Data: DELC(NROW)
    Module: U1DREL

A subset of the following two-dimensional arrays are used to describe each layer. The arrays needed for each layer depend on the layer type code (LAYCON) and whether the simulation is transient (ISS = 0) or steady state (ISS not 0). If an array is not needed, it must be omitted. All of the arrays (items 5-13) for layer 1 are read first; then all of the arrays for layer 2, etc.

IF THE SIMULATION IS TRANSIENT (ISS not 0)

5. Data: SC1(NCOL,NROW)
    Module: U2DREL

IF THE LAYER-TYPE CODE (LAYCON) IS 0 OR 2

6. Data: CR(NCOL,NROW)
    Module: U2DREL

7. Data: CC(NCOL,NROW)
    Module: U2DREL

IF THE LAYER-TYPE CODE (LAYCON) IS 1 OR 3

8. Data: CDTR(NCOL,NROW)
    Module: U2DREL

9. Data: CDTC(NCOL,NROW)
    Module: U2DREL

10. Data: BOT(NCOL,NROW)
    Module: U2DREL

IF THE LAYER IS NOT THE BOTTOM LAYER

     11. Data: CV(NCOL,NROW)
            Module: U2DREL

IF THE SIMULATION IS TRANSIENT (ISS not 0) AND THE LAYER-TYPE CODE (LAYCON) IS 2 OR 3

     12. Data: SC2(NCOL,NROW)
            Module: U2DREL

IF THE LAYER-TYPE CODE IS 2 OR 3

     13. Data: TOP(NCOL,NROW)
            Module: U2DREL

Definition of Input Parameters

ISS--is the steady-state flag.

    If ISS is not 0, the simulation is steady state.

    If ISS = 0, the simulation is transient.

IGFDCB--is a flag and a unit number.

    If IGFDCB > 0, it is the unit number on which cell-by-cell flow terms will be recorded whenever ICBCFL is set. ICBCFL is an input item in the Output Control option of the model (McDonald and Harbaugh, 1988, p. 4-14).

    If IGFDCB = 0, cell-by-cell flow terms will not be printed or recorded.

    If IGFDCB < 0, flow for each constant-head cell will be printed whenever ICBCFL is set.

LAYCON--is the layer-type code array. Each element holds the code for the respective layer. Read one value for each layer. There is a limit of 80 layers. Leave unused elements blank.

    0 - CONFINED--Horizontal conductance and storage capacity of the layer are constant for the entire simulation.

    1 - UNCONFINED--Horizontal conductance of the layer varies. It is calculated from the saturated thickness and the conductance divided by thickness. The storage capacity is constant; this value is valid only for layer 1.

2 - CONFINED/UNCONFINED--Horizontal conductance of the layer is constant. The storage capacity may be either confined or unconfined. Vertical flow from above is limited while unconfined.

3 - CONFINED/UNCONFINED--Horizontal conductance of the layer varies. It is calculated from the saturated thickness and conductance divided by thickness. The storage capacity may be either confined or unconfined. Vertical flow from above is limited while unconfined.

DELR--is the cell width along rows. Read one value for each of the NCOL columns.

DELC--is the cell width along columns. Read one value for each of the NROW rows.

SC1--is the primary storage capacity. Read SC1 only for a transient simulation (steady-state flag, ISS, is 0). If LAYCON is 1 (strictly unconfined), SC1 is equal to specific yield multiplied by cell area; if LAYCON is 2 or 3, SC1 is confined storage coefficient multiplied by cell area. If LAYCON is 0, the layer is normally confined and SC1 would then be the confined storage coefficient multiplied by cell area. However, layer-type 0 can be used to simulate an unconfined aquifer if saturated thickness changes are small compared to total saturated thickness and if there is negligible flow from above; in this case, SC1 would be specific yield multiplied by cell area.

CR--is the conductance along rows. Read CR only for layers where LAYCON is 0 or 2. The value of CR for node (i,j,k) represents conductance between that node and node (i,j+1,k).

CC--is the conductance along columns. Read CC only for layers where LAYCON is 0 or 2. The value of CC for node (i,j,k) represents conductance between that node and node (i+1,j,k).

CDTR--is the conductance divided by thickness along rows. Read CDTR only for layers where LAYCON is 1 or 3. The value of CDTR for node (i,j,k) represents conductance divided by thickness between that node and node (i,j+1,k).

CDTC--is the conductance divided by thickness along columns. Read CDTC only for layers where LAYCON is 1 or 3. The value of CDTC for node (i,j,k) represents conductance divided by thickness between that node and node (i+1,j,k).

BOT--is the elevation of the aquifer bottom. Read BOT only for layers where LAYCON is 1 or 3.

CV--is the vertical conductance. The value of CV for node (i,j,k) represents conductance between that node and node (i,j,k+1). Because there is not a layer beneath the bottom layer, CV is not required for the bottom layer and must not be included in the data.

SC2--is the secondary storage capacity. Read SC2 only for layers where LAYCON is 2 or 3 and only if a transient simulation (steady-state flag, ISS, is 0). The secondary storage capacity is always specific yield multiplied by cell area.

TOP--is the elevation of the aquifer top. Read TOP only for layers where LAYCON is 2 or 3.

SAMPLE PROBLEM

To demonstrate the use of the GFD Package, the sample problem from McDonald and Harbaugh (1988, Appendix D) has been executed using the GFD Package. The GFD input data is shown in Table 1. Layer 1, simulated as an unconfined aquifer (LAYCON=1), requires CDT values, which are calculated as hydraulic conductivity times cell width divided by distance between nodes (equation 3). Horizontal cell dimensions are a constant 5000 ft in both horizontal directions, and assuming that nodes are still centered in cells, the distance between adjacent nodes is 5000 ft. Thus, cell width divided by distance between nodes is one because of the uniform cell spacing in both directions. The resulting CDT values are uniform in both directions for all cells in the layer; CDTR and CDTC for layer 1 are .001 ft/s. Layers 2 and 3 are simulated as confined aquifers, and conductance is required. For each of these layers, transmissivity is uniform. Conductance is calculated as the product of transmissivity times cell width divided by distance between nodes (equation 2). The result is that conductances along rows (CR) and columns (CC) are the same for all cells in each layer. Conductance in layer 2 is 0.01 ft^2/s, and 0.02 ft^2/s for layer 3. Vertical conductance (CV) is the value for VCONT from the BCF Package multiplied by cell area. The resulting value for CV between layers 1 and 2 is 0.5 ft^2/s; the value is 0.25 ft^2/s between layers 2 and 3.

Table 1. -- Sample problem input data for the GFD Package

[Note that parameter names, such as DELC, are included in the following records in order to help identify the data. Such labels, or any desired information, can be included in the actual input data read by the model program provided that the added information does not occupy any area of a record used for data. Extra records cannot be included.]

```
        1         0     ISS,IGFDBD
1 0 0                   LAYCON
        0      5000.                       DELR
        0      5000.                       DELC
        0       .001                       CDTR, layer 1
        0       .001                       CDTC, layer 1
        0      -150.                       BOT, layer 1
        0        .5                        CV, layer 1
        0       .01                        CR, layer 2
        0       .01                        CC, layer 2
        0       .25                        CV, layer 2
        0       .02                        CR, layer 3
        0       .02                        CC, layer 3
```

The input to the Basic Package is unchanged except IUNIT(1) is set to 0 and IUNIT(14) is set to 11 to deactivate the BCF Package and activate the GFD Package. Input for all the other packages is unchanged from that shown in McDonald and Harbaugh (1988, Appendix D).

The results from running the sample problem using the GFD Package are shown in Table 2. The heads are nearly equal to those from McDonald and Harbaugh (1988); the differences can be attributed to the different formulation of conductance for the top layer. The GFD Package assumes a uniform CDT and linearly varying saturated thickness between nodes. The BCF Package assumes a constant saturated thickness and hydraulic conductivity in each cell. If heads were exactly the same in both simulations, the assumptions used in the GFD Package would result in slightly higher conductances than the conductances calculated by the BCF Package. The higher conductances would cause too much water to flow through the system, which would cause heads to decrease in order to correctly solve the flow equation. Thus, heads in the GFD simulation are slightly lower than heads in the BCF simulation.

Table 2.--Output from the sample problem

```
             U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER MODEL


SAMPLE PROBLEM FROM TWRI 6-A1 -- HEAD DIFFERS SLIGHTLY DUE TO MODIFIED CONDUCTANCE CALCULATION FOR WATER-TABLE LAYER
   3 LAYERS         15 ROWS         15 COLUMNS
   1 STRESS PERIOD(S) IN SIMULATION
MODEL TIME UNIT IS SECONDS


I/O UNITS:
ELEMENT OF IUNIT:  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
        I/O UNIT:  0 12 13  0  0  0  0 18 19  0  0  0  0  0 11  0  0  0  0  0  0  0  0  0


BAS1 -- BASIC MODEL PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT  1
ARRAYS RHS AND BUFF WILL SHARE MEMORY.
START HEAD WILL NOT BE SAVED -- DRAWDOWN CANNOT BE CALCULATED                   .
    5892 ELEMENTS IN X ARRAY ARE USED BY BAS
    5892 ELEMENTS OF X ARRAY USED OUT OF  350000


GFD1 -- GENERAL FINITE-DIFFERENCE FLOW PACKAGE, VERSION 1, 9/19/89 INPUT READ FROM UNIT 11
STEADY-STATE SIMULATION
     LAYER  AQUIFER TYPE
     -------------------
       1         1
       2         0
       3         0
     675 ELEMENTS IN X ARRAY ARE USED BY GFD
    6567 ELEMENTS OF X ARRAY USED OUT OF  350000


WEL1 -- WELL PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM 12
MAXIMUM OF    15 WELLS
      60 ELEMENTS IN X ARRAY ARE USED FOR WELLS
    6627 ELEMENTS OF X ARRAY USED OUT OF  350000


DRN1 -- DRAIN PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT 13
MAXIMUM OF     9 DRAINS
      45 ELEMENTS IN X ARRAY ARE USED FOR DRAINS
    6672 ELEMENTS OF X ARRAY USED OUT OF  350000


RCH1 -- RECHARGE PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT 18
OPTION 1 -- RECHARGE TO TOP LAYER
     225 ELEMENTS OF X ARRAY USED FOR RECHARGE
    6897 ELEMENTS OF X ARRAY USED OUT OF  350000


SIP1 -- STRONGLY IMPLICIT PROCEDURE SOLUTION PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT 19
MAXIMUM OF  50 ITERATIONS ALLOWED FOR CLOSURE
  5 ITERATION PARAMETERS
    2905 ELEMENTS IN X ARRAY ARE USED BY SIP
    9802 ELEMENTS OF X ARRAY USED OUT OF  350000
```

Table 2.--Output from the sample problem (Cont.)

SAMPLE PROBLEM FROM TWRI 6-A1 -- HEAD DIFFERS SLIGHTLY DUE TO MODIFIED CONDUCTANCE CALCULATION FOR WATER-TABLE LAYER

BOUNDARY ARRAY FOR LAYER 1 WILL BE READ ON UNIT 1 USING FORMAT: (15I3)

```
        1   2   3   4   5   6   7   8   9  10  11  12  13  14  15
.....................................................................

 1     -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1

 2     -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1

 3     -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1

 4     -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1

 5     -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1

 6     -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1

 7     -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1

 8     -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1

 9     -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1

10     -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1

11     -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1

12     -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1

13     -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1

14     -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1

15     -1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
```

Table 2.--Output from the sample problem (Cont.)

BOUNDARY ARRAY FOR LAYER 2 WILL BE READ ON UNIT 1 USING FORMAT: (15I3)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 2.--Output from the sample problem (Cont.)

```
                                        BOUNDARY ARRAY =              1 FOR LAYER  3

AQUIFER HEAD WILL BE SET TO  999.99     AT ALL NO-FLOW NODES (IBOUND=0).

                                         INITIAL HEAD =  0.0000000      FOR LAYER  1

                                         INITIAL HEAD =  0.0000000      FOR LAYER  2

                                         INITIAL HEAD =  0.0000000      FOR LAYER  3

DEFAULT OUTPUT CONTROL -- THE FOLLOWING OUTPUT COMES AT THE END OF EACH STRESS PERIOD:
TOTAL VOLUMETRIC BUDGET
          HEAD

                                                 DELR =    5000.000

                                                 DELC =    5000.000

                             COND/THICK ALONG ROWS =  0.9999999E-03 FOR LAYER  1

                             COND/THICK ALONG COLS =  0.9999999E-03 FOR LAYER  1

                                               BOTTOM =  -150.0000      FOR LAYER  1

                             VERTICAL CONDUCTANCE =  0.5000000      FOR LAYER  1

                          CONDUCTANCE ALONG ROWS =  0.1000000E-01 FOR LAYER  2

                          CONDUCTANCE ALONG COLS =  0.1000000E-01 FOR LAYER  2

                             VERTICAL CONDUCTANCE =  0.2500000      FOR LAYER  2

                          CONDUCTANCE ALONG ROWS =  0.2000000E-01 FOR LAYER  3

                          CONDUCTANCE ALONG COLS =  0.2000000E-01 FOR LAYER  3

                              SOLUTION BY THE STRONGLY IMPLICIT PROCEDURE
                              ---------------------------------------------

           MAXIMUM ITERATIONS ALLOWED FOR CLOSURE =        50
                         ACCELERATION PARAMETER =     1.0000
               HEAD CHANGE CRITERION FOR CLOSURE =     0.10000E-02
                SIP HEAD CHANGE PRINTOUT INTERVAL =         1
```

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Table 2.--Output from the sample problem (Cont.)

```
5 ITERATION PARAMETERS CALCULATED FROM SPECIFIED WSEED = 0.00100000 :

   0.0000000E+00   0.8221720E+00   0.9683772E+00   0.9943765E+00   0.9990000E+00
```

```
                              STRESS PERIOD NO.   1, LENGTH =   86400.00
                              ------------------------------------------------

                              NUMBER OF TIME STEPS =      1

                               MULTIPLIER FOR DELT =      1.000

                            INITIAL TIME STEP SIZE =   86400.00
```

```
15 WELLS
                    LAYER    ROW    COL    STRESS RATE   WELL NO.
                    ----------------------------------------------
                      3       5     11     -5.0000         1
                      2       4      6     -5.0000         2
                      2       6     12     -5.0000         3
                      1       9      8     -5.0000         4
                      1       9     10     -5.0000         5
                      1       9     12     -5.0000         6
                      1       9     14     -5.0000         7
                      1      11      8     -5.0000         8
                      1      11     10     -5.0000         9
                      1      11     12     -5.0000        10
                      1      11     14     -5.0000        11
                      1      13      8     -5.0000        12
                      1      13     10     -5.0000        13
                      1      13     12     -5.0000        14
                      1      13     14     -5.0000        15
```

```
9 DRAINS
           LAYER    ROW    COL    ELEVATION   CONDUCTANCE   DRAIN NO.
           ---------------------------------------------------------
             1       8      2     0.0000        1.000         1
             1       8      3     0.0000        1.000         2
             1       8      4     10.00         1.000         3
             1       8      5     20.00         1.000         4
             1       8      6     30.00         1.000         5
             1       8      7     50.00         1.000         6
             1       8      8     70.00         1.000         7
             1       8      9     90.00         1.000         8
             1       8     10     100.0         1.000         9
```

```
                                        RECHARGE =  0.3000000E-07
```

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Table 2.--Output from the sample problem (Cont.)

```
 31 ITERATIONS FOR TIME STEP   1 IN STRESS PERIOD  1

MAXIMUM HEAD CHANGE FOR EACH ITERATION:

HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW,COL
-----------------------------------------------------------------------------------------------------------------------------------
   -22.41    ( 3,  5, 11)   12.48    ( 1,  1, 15)   13.39    ( 3,  1, 14)   48.20    ( 1,  1, 15)   35.87    ( 3,  1, 13)
    2.481    ( 1,  9, 14)   1.429    ( 3, 10, 13)   6.210    ( 1, 12, 14)   7.405    ( 3, 11, 14)   13.64    ( 1, 15, 15)
   0.5474    ( 3,  8,  7)  0.4805    ( 2,  6,  9)  0.4700    ( 3,  5, 10)   2.015    ( 1, 11, 14)   2.296    ( 3,  5, 13)
   0.1105    ( 1, 13, 12)  0.7037E-01 ( 3, 12, 11) 0.2809    ( 1, 14, 14)  0.3130    ( 3, 13, 14) 0.3299    ( 1, 15, 15)
 0.7809E-02  ( 1, 13, 12) 0.1580E-01 ( 2, 11, 11) 0.1770E-01 ( 3, 11, 10) 0.7875E-01 ( 1, 14, 14) 0.8456E-01 ( 3,  7, 14)
 0.4147E-02  ( 1, 13, 14) 0.2542E-02 ( 3, 14, 15) 0.9710E-02 ( 1, 14, 14) 0.1076E-01 ( 3, 13, 14) 0.1019E-01 ( 1, 15, 15)
 0.2408E-03  ( 1, 13, 12)
```

Table 2.--Output from the sample problem (Cont.)

HEAD IN LAYER 1 AT END OF TIME STEP 1 IN STRESS PERIOD 1

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
	11	12	13	14	15					
1	0.0000	24.86	43.91	59.16	71.74	82.44	91.84	99.97	106.9	112.6
	117.3	121.2	124.2	126.3	127.4					
2	0.0000	24.36	43.01	57.89	70.09	80.50	90.05	98.33	105.2	110.9
	115.6	119.5	122.7	124.9	126.0					
3	0.0000	23.37	41.21	55.35	66.70	76.14	86.45	95.14	102.1	107.5
	112.0	116.1	119.6	122.0	123.3					
4	0.0000	21.85	38.53	51.68	61.73	67.97	81.28	90.69	97.58	102.5
	106.0	110.7	114.9	117.8	119.3					
5	0.0000	19.68	34.85	47.25	57.63	66.68	77.03	85.71	92.17	96.09
	97.24	103.1	108.8	112.5	114.3					
6	0.0000	16.47	29.45	40.85	51.25	61.16	71.14	79.80	86.42	90.77
	92.98	94.18	102.0	106.4	108.4					
7	0.0000	11.53	21.07	31.17	41.36	51.81	63.04	72.64	79.91	84.87
	88.55	91.62	96.38	99.77	101.8					
8	0.0000	3.479	6.830	16.25	26.30	36.96	52.57	64.27	72.48	77.21
	81.94	84.96	89.22	91.67	94.29					
9	0.0000	10.53	19.08	28.10	36.90	45.25	52.93	55.35	65.11	66.03
	73.89	73.74	80.79	80.12	86.45					
10	0.0000	14.60	25.83	35.35	43.46	50.08	54.90	57.51	62.91	65.51
	70.34	72.39	76.67	78.21	81.75					
11	0.0000	17.08	29.91	39.97	47.74	53.20	55.77	53.29	60.23	59.25
	66.39	65.41	72.18	71.00	77.58					
12	0.0000	18.64	32.51	43.02	50.77	55.88	58.29	58.43	61.89	63.14
	67.08	68.46	72.25	73.41	76.81					
13	0.0000	19.62	34.18	45.08	52.96	57.99	59.86	56.71	62.55	60.87
	67.18	65.71	71.86	70.31	76.44					
14	0.0000	20.22	35.21	46.42	54.56	60.03	63.13	64.47	67.21	68.74
	71.60	73.13	75.79	76.98	79.05					
15	0.0000	20.50	35.71	47.10	55.43	61.21	64.98	67.48	69.90	71.97
	74.24	76.17	78.17	79.62	80.78					

Table 2.--Output from the sample problem (Cont.)

HEAD IN LAYER 2 AT END OF TIME STEP 1 IN STRESS PERIOD 1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.0000	24.58	43.63	58.92	71.53	82.24	91.65	99.80	106.7	112.4	117.2	121.1	124.1	126.2	127.2
2	0.0000	24.09	42.73	57.65	69.87	80.29	89.86	98.16	105.1	110.8	115.4	119.4	122.5	124.7	125.9
3	0.0000	23.10	40.94	55.11	66.46	75.70	86.22	94.96	101.9	107.4	111.8	115.9	119.4	121.9	123.1
4	0.0000	21.59	38.26	51.43	61.28	60.11	80.84	90.49	97.39	102.2	105.3	110.4	114.7	117.7	119.2
5	0.0000	19.43	34.59	47.01	57.38	66.24	76.80	85.51	91.94	95.36	91.04	102.1	108.5	112.3	114.1
6	0.0000	16.23	29.20	40.60	51.02	60.93	70.93	79.60	86.23	90.49	92.01	86.18	101.6	106.2	108.2
7	0.0000	11.36	20.92	31.01	41.21	51.66	62.86	72.44	79.72	84.68	88.30	91.19	96.17	99.60	101.6
8	0.0000	4.205	8.326	17.58	27.57	38.24	52.93	64.15	72.30	77.07	81.76	84.81	89.05	91.54	94.12
9	0.0000	10.37	18.94	27.96	36.77	45.14	52.84	56.10	65.04	66.75	73.82	74.44	80.72	80.80	86.33
10	0.0000	14.37	25.58	35.12	43.24	49.88	54.73	57.45	62.76	65.44	70.20	72.33	76.53	78.15	81.59
11	0.0000	16.84	29.66	39.74	47.52	53.01	55.64	54.06	60.16	60.00	66.33	66.14	72.12	71.71	77.47
12	0.0000	18.39	32.26	42.80	50.56	55.69	58.12	58.37	61.74	63.08	66.93	68.40	72.11	73.36	76.65
13	0.0000	19.38	33.93	44.86	52.75	57.80	59.74	57.46	62.48	61.61	67.12	66.44	71.80	71.01	76.33
14	0.0000	19.97	34.96	46.20	54.35	59.83	62.95	64.35	67.04	68.62	71.43	73.01	75.63	76.87	78.88
15	0.0000	20.25	35.46	46.88	55.22	61.02	64.79	67.30	69.72	71.80	74.07	76.00	78.00	79.45	80.60

Table 2.--Output from the sample problem (Cont.)

```
            HEAD IN LAYER  3 AT END OF TIME STEP  1 IN STRESS PERIOD  1
      ------------------------------------------------------------------------

            1         2         3         4         5         6         7         8         9         10
            11        12        13        14        15


       1    1.795     24.26     43.27     58.61     71.24     81.98     91.41     99.56     106.5     112.2
            117.0     120.9     123.9     126.0     127.1

       2    1.758     23.77     42.37     57.33     69.58     80.00     89.61     97.92     104.9     110.5
            115.2     119.2     122.3     124.5     125.7

       3    1.685     22.79     40.59     54.79     66.13     75.21     85.92     94.71     101.7     107.1
            111.5     115.7     119.2     121.7     122.9

       4    1.573     21.29     37.91     51.09     60.78     62.63     80.35     90.22     97.14     101.8
            104.1     110.0     114.5     117.5     119.0

       5    1.412     19.14     34.24     46.68     57.04     65.74     76.48     85.24     91.62     94.12
            77.41     100.6     108.2     112.1     113.9

       6    1.174     15.96     28.86     40.28     50.71     60.62     70.65     79.33     85.96     90.07
            90.55     88.50     101.1     105.9     108.0

       7    0.8258    11.19     20.76     30.85     41.06     51.51     62.64     72.18     79.46     84.42
            87.94     90.72     95.89     99.37     101.4

       8    0.4326    5.126     10.18     19.26     29.18     39.83     53.39     64.03     72.07     76.91
            81.53     84.64     88.83     91.39     93.90

       9    0.7533    10.21     18.80     27.82     36.64     45.04     52.75     56.99     64.98     67.60
            73.77     75.26     80.67     81.59     86.19

      10    1.037     14.10     25.26     34.81     42.96     49.62     54.51     57.40     62.57     65.40
            70.01     72.29     76.35     78.11     81.39

      11    1.222     16.56     29.33     39.43     47.24     52.75     55.49     54.97     60.12     60.90
            66.29     67.02     72.08     72.56     77.34

      12    1.338     18.11     31.92     42.49     50.28     55.43     57.90     58.33     61.56     63.04
            66.75     68.36     71.93     73.32     76.45

      13    1.412     19.09     33.59     44.56     52.48     57.55     59.59     58.35     62.44     62.49
            67.07     67.30     71.76     71.86     76.20

      14    1.456     19.68     34.62     45.90     54.08     59.58     62.71     64.20     66.82     68.48
            71.22     72.87     75.43     76.73     78.67

      15    1.477     19.96     35.12     46.58     54.95     60.76     64.54     67.06     69.48     71.56
            73.83     75.77     77.77     79.22     80.38
```

Table 2.--Output from the sample problem (Cont.)

VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 1 IN STRESS PERIOD 1

```
    CUMULATIVE VOLUMES      L**3                        RATES FOR THIS TIME STEP      L**3/T
    ------------------                                  ------------------------

            IN:                                                 IN:
            ---                                                 ---
        STORAGE =   0.00000                                 STORAGE =   0.00000
 CONSTANT HEAD =   0.00000                          CONSTANT HEAD =   0.00000
          WELLS =   0.00000                                   WELLS =   0.00000
         DRAINS =   0.00000                                  DRAINS =   0.00000
       RECHARGE =   0.13608E+08                             RECHARGE =   157.50


       TOTAL IN =   0.13608E+08                             TOTAL IN =   157.50

           OUT:                                                OUT:
           ----                                                ----
        STORAGE =   0.00000                                 STORAGE =   0.00000
 CONSTANT HEAD =   0.43291E+07                       CONSTANT HEAD =   50.105
          WELLS =   0.64800E+07                                WELLS =   75.000
         DRAINS =   0.27985E+07                               DRAINS =   32.390
       RECHARGE =   0.00000                                  RECHARGE =   0.00000


      TOTAL OUT =   0.13608E+08                            TOTAL OUT =   157.50


        IN - OUT =   406.00                                 IN - OUT =   0.46997E-02


PERCENT DISCREPANCY =            0.00           PERCENT DISCREPANCY =            0.00
```

```
      TIME SUMMARY AT END OF TIME STEP  1 IN STRESS PERIOD  1
                         SECONDS       MINUTES       HOURS        DAYS         YEARS
                        -----------------------------------------------------------------
       TIME STEP LENGTH     86400.0       1440.00      24.0000      1.00000     0.273785E-02
     STRESS PERIOD TIME     86400.0       1440.00      24.0000      1.00000     0.273785E-02
  TOTAL SIMULATION TIME     86400.0       1440.00      24.0000      1.00000     0.273785E-02
```

MODULE DOCUMENTATION

The modules (subroutines) for the GFD Package closely follow the design of the BCF Package modules. GFD has one less module becuase two modules were combined into one. Because of the similarity of design, including in most cases identical comments, flowcharts and detailed narratives are not included here. Instead, a brief narrative describes differences between the corresponding GFD and BCF Package modules. A listing of each module and a list of variables are provided.

Statements must be added to the MAIN program to call the GFD Package modules. There are four calls to GFD Package modules -- GFD1AL, GFD1RP, GFD1FM, and GFD1BD. Add the GFD call statements immediately following the corresponding call statements for the BCF Package. For example, the GFD1AL call should immediately follow the BCF1AL call. The calling statements are:

```
      IF(IUNIT(14).GT.0) CALL GFD1AL(ISUM,LENX,LCSC1,LCCDTR,LCCDTC,
     1      LCBOT,LCTOP,LCSC2,IUNIT(14),ISS,NCOL,NROW,NLAY,IOUT,IGFDCB)

      IF(IUNIT(14).GT.0) CALL GFD1RP(X(LCIBOU),X(LCHNEW),X(LCSC1),
     1          X(LCCDTR),X(LCCDTC),X(LCCR),X(LCCC),X(LCCV),X(LCDELR),
     2          X(LCDELC),X(LCBOT),X(LCTOP),X(LCSC2),
     3          IUNIT(14),ISS,NCOL,NROW,NLAY,NODES,IOUT)

      IF(IUNIT(14).GT.0) CALL GFD1FM(X(LCHCOF),X(LCRHS),X(LCHOLD),
     1          X(LCSC1),X(LCHNEW),X(LCIBOU),X(LCCR),X(LCCC),X(LCCV),
     2          X(LCCDTR),X(LCCDTC),X(LCBOT),X(LCTOP),X(LCSC2),
     3          DELT,ISS,KKITER,KKSTP,KKPER,NCOL,NROW,NLAY,IOUT)

      IF(IUNIT(14).GT.0) CALL GFD1BD(VBNM,VBVL,MSUM,X(LCHNEW),
     1      X(LCIBOU),X(LCHOLD),X(LCSC1),X(LCCR),X(LCCC),X(LCCV),
     2      X(LCTOP),X(LCSC2),DELT,ISS,NCOL,NROW,NLAY,KKSTP,KKPER,
     3      IGFDCB,ICBCFL,X(LCBUFF),IOUT)
```

The above statements call the GFD Package whenever the 14th element of the IUNIT array is greater than 0. Another IUNIT element can be substituted if desired. To do this, replace IUNIT(14) in the "IF" statements and in the calling arguments.

Modules GFD1AL and GFD1RP are very similar to the corresponding BCF Package modules. The differences are in the specific arrays being allocated and read. For example, an anisotropy array is not needed in GFD because anisotropy is incorporated in conductance terms; for unconfined and convertible layers conductance divided by thickness (CDTR and CDTC arrays) are used by GFD instead of hydraulic conductivity (HY array).

Module GFD1FM is essentially identical to the corrsponding BCF Package module. The changes all result from a change in a submodule, SGFD1H, which calculates conductance for unconfined and convertible layers. SGFD1H requires different arguments than did the analogous BCF Package module (SBCF1H), and these arguments must be passed through GFD1FM. The statements in GFD1FM that are not involved with calling SGFD1H are identical to those in BCF1FM.

Module GFD1BD is identical to module BCF1BD other than the calls to submodule. Submodules SGFD1F and SGFD1B are called rather than SBCF1F and SBCF1B.

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Module SGFD1N is a simplified version of SBCF1N. There is less initialization work because conductance and storage input parameters more closely match the fundamental data used in the flow equation.

Module SGFD1H calculates horizontal conductance for unconfined and convertible layers. First it calculates saturated thickness using aquifer bottom elevation, aquifer top elevation if appropriate, and the current head. Then it calculates conductance from saturated thickness and conductance divided by thickness. This module provides the analogous functions of modules SBCF1H and SBCF1C in the BCF Package. SBCF1H calculates saturated thickness and transmissivity; SBCF1C calculates conductance from transmissivity and cell dimensions. SBCF1C was separated from SBCF1H because the calculation of conductance from transmissivity was also required by module SBCF1N for confined layers. By putting the transmissivity calculation in a separate module, duplication of this code was avoided. The GFD Package does not require the calculation of conductance by module SGFD1N for confined layers. SGFD1H is the only module that requires conductance calculations. Thus, there is no reason to have separate modules for calculating saturated thickness and conductance. The steps and structure in SGFD1H closely match those of routines SBCF1H and SBCF1C combined.

Modules SGFD1B and SGFD1F are identical to SBCF1B and SBCF1F, except that variable IGFDCB replaces variable IBCFCB.

Memory requirements for GFD data are similar to BCF memory requirements. Most data in the model are stored in the X array (McDonald and Harbaugh, 1988, p. 3-22 and Appendix B-1), and the dimensioned size of the X array must be large enough to hold the data used by all packages. The X-array requirements for the GFD Package can be calculated by adding the space required for each GFD option.

A.   If a transient simulation (ISS is 0), add NCOL*NROW*NLAY.
B.   For each layer where LAYCON is one or three, add 3*NCOL*NROW.
C.   For each layer where LAYCON is two or three, add NCOL*NROW.
D.   If a transient simulation (ISS is 0), for each layer where LAYCON is two or three, add NCOL*NROW.

```
      SUBROUTINE GFD1AL(ISUM,LENX,LCSC1,LCCDTR,LCCDTC,LCBOT,
     1      LCTOP,LCSC2,IN,ISS,NCOL,NROW,NLAY,IOUT,IGFDCB)
C
C-----VERSION 1304 19SEP1989 GFD1AL
C
C     ****************************************************************
C     ALLOCATE ARRAY STORAGE FOR GENERAL FINITE-DIFFERENCE FLOW PACKAGE
C     ****************************************************************
C
C        SPECIFICATIONS:
C     ----------------------------------------------------------------
      COMMON /FLWCOM/LAYCON(80)
C     ----------------------------------------------------------------
C
C1------IDENTIFY PACKAGE
      WRITE(IOUT,1)IN
    1 FORMAT(1H0,'GFD1 -- GENERAL FINITE-DIFFERENCE FLOW PACKAGE, ',
     1      'VERSION 1, 9/19/89 INPUT READ FROM UNIT',I3)
C
C2------READ AND PRINT ISS (STEADY-STATE FLAG) AND IGFDCB (FLAG FOR
C2------PRINTING OR UNIT# FOR RECORDING CELL-BY-CELL FLOW TERMS)
      READ(IN,2) ISS,IGFDCB
    2 FORMAT(2I10)
      IF(ISS.EQ.0) WRITE(IOUT,3)
    3 FORMAT(1X,'TRANSIENT SIMULATION')
      IF(ISS.NE.0) WRITE(IOUT,4)
    4 FORMAT(1X,'STEADY-STATE SIMULATION')
      IF(IGFDCB.GT.0) WRITE(IOUT,9) IGFDCB
    9 FORMAT(1X,'CELL BUDGET WILL BE SAVED ON UNIT',I3)
      IF(IGFDCB.LT.0) WRITE(IOUT,88)
   88 FORMAT(1X,'CONSTANT HEAD CELL-BY-CELL FLOWS WILL BE PRINTED')
C
C3------READ TYPE CODE FOR EACH LAYER AND COUNT TOPS AND BOTTOMS
      IF(NLAY.LE.80) GO TO 50
      WRITE(IOUT,11)
   11 FORMAT(1H0,'YOU HAVE SPECIFIED MORE THAN 80 MODEL LAYERS'/1X,
     1  'SPACE IS RESERVED FOR A MAXIMUM OF 80 LAYERS IN ARRAY LAYCON')
      STOP
C
C3A-----READ LAYER TYPE CODES.
   50 READ(IN,51) (LAYCON(I),I=1,NLAY)
   51 FORMAT(40I2)
C          BOTTOM IS READ FOR TYPES 1,3    TOP IS READ FOR TYPES 2,3
      WRITE(IOUT,52)
   52 FORMAT(1X,5X,'LAYER  AQUIFER TYPE',/1X,5X,19('-'))
C
C3B-----INITIALIZE TOP AND BOTTOM COUNTERS.
      NBOT=0
      NTOP=0
C
C3C------PRINT LAYER TYPE AND COUNT TOPS AND BOTTOMS NEEDED.
      DO 100 I=1,NLAY
C
C3C1----PRINT LAYER NUMBER AND LAYER TYPE CODE.
      L=LAYCON(I)
      WRITE(IOUT,7) I,L
    7 FORMAT(1X,I9,I10)
```

```
C
C3C2----ONLY THE TOP LAYER CAN BE UNCONFINED(LAYCON=1).
       IF(L.NE.1 .OR. I.EQ.1) GO TO 70
       WRITE(IOUT,8)
     8 FORMAT(1H0,'AQUIFER TYPE 1 IS ONLY ALLOWED IN TOP LAYER')
       STOP
C
C3C3----LAYER TYPES 1 AND 3 NEED A BOTTOM. ADD 1 TO KB.
    70 IF(L.EQ.1 .OR. L.EQ.3) NBOT=NBOT+1
C
C3C4----LAYER TYPES 2 AND 3 NEED A TOP. ADD 1 TO KT.
       IF(L.EQ.2 .OR. L.EQ.3) NTOP=NTOP+1
   100 CONTINUE
C
C
C
C4------COMPUTE DIMENSIONS FOR ARRAYS.
       NRC=NROW*NCOL
       ISIZ=NRC*NLAY
C
C5------ALLOCATE SPACE FOR ARRAYS. IF RUN IS TRANSIENT(ISS=0)
C5------THEN SPACE MUST BE ALLOCATED FOR STORAGE.
       ISOLD=ISUM
       LCSC1=ISUM
       IF(ISS.EQ.0) ISUM=ISUM+ISIZ
       LCSC2=ISUM
       IF(ISS.EQ.0) ISUM=ISUM+NRC*NTOP
       LCBOT=ISUM
       ISUM=ISUM+NRC*NBOT
       LCCDTR=ISUM
       ISUM=ISUM+NRC*NBOT
       LCCDTC=ISUM
       ISUM=ISUM+NRC*NBOT
       LCTOP=ISUM
       ISUM=ISUM+NRC*NTOP
C
C6------PRINT THE AMOUNT OF SPACE USED BY THE GFD PACKAGE.
       ISP=ISUM-ISOLD
       WRITE(IOUT,101) ISP
   101 FORMAT(1X,I8,' ELEMENTS IN X ARRAY ARE USED BY GFD')
       ISUM1=ISUM-1
       WRITE(IOUT,102) ISUM1,LENX
   102 FORMAT(1X,I8,' ELEMENTS OF X ARRAY USED OUT OF',I8)
       IF(ISUM1.GT.LENX) WRITE(IOUT,103)
   103 FORMAT(1X,'    ***X ARRAY MUST BE DIMENSIONED LARGER***')
C
C7------RETURN
       RETURN
       END
```

List of Variables for Module GFD1AL

Variable	Range	Definition
I	Module	Index
IGFDCB	Package	Flag and a unit number.
		> 0, unit number on which cell-by-cell flow terms will be recorded whenever ICBCFL is set.
		= 0, cell-by-cell flow terms will not be printed or recorded.
		< 0, flow from each constant-head cell will be printed whenever ICBCFL is set.
IN	Package	Primary unit number from which input for this package will be read.
IOUT	Global	Primary unit number for all printed output.
ISIZ	Module	Number of cells in the grid.
ISOLD	Module	Value of ISUM upon entry to this module.
ISP	Module	Number of elements in the X array allocated by this module.
ISS	Package	Steady-state flag.
		= 0, simulation is transient
		not 0, simulation is steady state.
ISUM	Global	Element number of the lowest element in the X array that has not yet been allocated. When space is allocated in the X array, the size of the allocation is added to ISUM.
ISUM1	Module	ISUM-1
L	Module	Temporary equivalent of LAYCON(I).
LAYCON	Package	DIMENSION (80) Layer-type code:
		0 -- Layer is strictly confined.
		1 -- Layer is strictly unconfined.
		2 -- Layer is convertible between confined and unconfined (saturated thickness is constant).
		3 -- Layer is convertible between confined and unconfined (saturated thickness varies).
LCBOT	Package	Location in the X array of the first element of array BOT.
LCCDTC	Package	Location in the X array of the first element of array CDTC.
LCCDTR	Package	Location in the X array of the first element of array CDTR.
LCSC1	Package	Location in the X array of the first element of array SC1.
LCSC2	Package	Location in the X array of the first element of array SC2.
LCTOP	Package	Location in the X array of the first element of array TOP.
LENX	Global	Number of elements in the X array. This should always be equal to the dimension of X specified in the MAIN program.
NBOT	Module	Counter for the number of layers that need elevation of the bottom and conductance divided by thickness arrays.
NCOL	Global	Number of columns in the grid.
NLAY	Global	Number of layers in the grid.
NRC	Module	Number of cells in a layer.
NROW	Global	Number of rows in the grid.
NTOP	Module	Counter for the number of layers that need elevation of the top and (if transient) secondary storage capacity arrays.

```
                              GFD1RP Module
                              -------------


          SUBROUTINE GFD1RP(IBOUND,HNEW,SC1,CDTR,CDTC,CR,CC,CV,DELR,DELC,
         1           BOT,TOP,SC2,IN,ISS,NCOL,NROW,NLAY,NODES,IOUT)
C
C-----VERSION 1406 19SEP1989 GFD1RP
C
C     ****************************************************************
C     READ AND INITIALIZE DATA FOR GENERAL FLOW PACKAGE
C     ****************************************************************
C
C        SPECIFICATIONS:
C     ----------------------------------------------------------------
      CHARACTER*4 ANAME
      DOUBLE PRECISION HNEW
C
      DIMENSION HNEW(NODES),SC1(NODES),CR(NODES),CC(NODES),CV(NODES),
     1          CDTR(NODES),CDTC(NODES),ANAME(6,11),DELR(NCOL),
     2          DELC(NROW),BOT(NODES),TOP(NODES),SC2(NODES),
     3          IBOUND(NODES)
C
      COMMON /FLWCOM/LAYCON(80)
C
      DATA ANAME(1,1),ANAME(2,1),ANAME(3,1),ANAME(4,1),ANAME(5,1),
     1  ANAME(6,1) /'PRIM','ARY ','STOR','AGE ','CAPA','CITY'/
      DATA ANAME(1,2),ANAME(2,2),ANAME(3,2),ANAME(4,2),ANAME(5,2),
     1  ANAME(6,2) /'  CO','NDUC','TANC','E AL','ONG ','ROWS'/
      DATA ANAME(1,3),ANAME(2,3),ANAME(3,3),ANAME(4,3),ANAME(5,3),
     1  ANAME(6,3) /'   C','OND/','THIC','K AL','ONG ','ROWS'/
      DATA ANAME(1,4),ANAME(2,4),ANAME(3,4),ANAME(4,4),ANAME(5,4),
     1  ANAME(6,4) /'    ','VERT','ICAL','  CON','DUCT','ANCE'/
      DATA ANAME(1,5),ANAME(2,5),ANAME(3,5),ANAME(4,5),ANAME(5,5),
     1  ANAME(6,5) /'    ','    ','    ','    ','  BO','TTOM'/
      DATA ANAME(1,6),ANAME(2,6),ANAME(3,6),ANAME(4,6),ANAME(5,6),
     1  ANAME(6,6) /'    ','    ','    ','    ','    ',' TOP'/
      DATA ANAME(1,7),ANAME(2,7),ANAME(3,7),ANAME(4,7),ANAME(5,7),
     1  ANAME(6,7) /'   S','EC. ','STOR','AGE ','CAPA','CITY'/
      DATA ANAME(1,8),ANAME(2,8),ANAME(3,8),ANAME(4,8),ANAME(5,8),
     1  ANAME(6,8) /'  CO','NDUC','TANC','E AL','ONG ','COLS'/
      DATA ANAME(1,9),ANAME(2,9),ANAME(3,9),ANAME(4,9),ANAME(5,9),
     1  ANAME(6,9) /'    ','    ','    ','    ','    ','DELR'/
      DATA ANAME(1,10),ANAME(2,10),ANAME(3,10),ANAME(4,10),ANAME(5,10),
     1  ANAME(6,10) /'    ','    ','    ','    ','    ','DELC'/
      DATA ANAME(1,11),ANAME(2,11),ANAME(3,11),ANAME(4,11),ANAME(5,11),
     1  ANAME(6,11) /'   C','OND/','THIC','K AL','ONG ','COLS'/
C     ----------------------------------------------------------------
C
C1------CALCULATE NUMBER OF NODES IN A LAYER AND READ DELR,DELC
      NIJ=NCOL*NROW
C
      CALL U1DREL(DELR,ANAME(1,9),NCOL,IN,IOUT)
      CALL U1DREL(DELC,ANAME(1,10),NROW,IN,IOUT)
C
C2------READ ALL PARAMETERS FOR EACH LAYER
      KT=0
      KB=0
      DO 200 K=1,NLAY
      KK=K
```

```
C
C2A-----FIND ADDRESS OF EACH LAYER IN THREE DIMENSION ARRAYS.
      IF(LAYCON(K).EQ.1 .OR. LAYCON(K).EQ.3) KB=KB+1
      IF(LAYCON(K).EQ.2 .OR. LAYCON(K).EQ.3) KT=KT+1
      LOC=1+(K-1)*NIJ
      LOCB=1+(KB-1)*NIJ
      LOCT=1+(KT-1)*NIJ
C
C2B-----READ PRIMARY STORAGE CAPACITY IF TRANSIENT SIMULATION
      IF(ISS.EQ.0)CALL U2DREL(SC1(LOC),ANAME(1,1),NROW,NCOL,KK,IN,IOUT)
C
C2C-----READ CONDUCTANCE IF LAYER TYPE IS 0 OR 2
      IF(LAYCON(K).EQ.3 .OR. LAYCON(K).EQ.1) GO TO 100
      CALL U2DREL(CR(LOC),ANAME(1,2),NROW,NCOL,KK,IN,IOUT)
      CALL U2DREL(CC(LOC),ANAME(1,8),NROW,NCOL,KK,IN,IOUT)
      GO TO 110
C
C2D-----READ SPECIFIC CONDUCTANCE AND BOTTOM ELEVATION(BOT)
C2D-----IF LAYER TYPE IS 1 OR 3
  100 CALL U2DREL(CDTR(LOCB),ANAME(1,3),NROW,NCOL,KK,IN,IOUT)
      CALL U2DREL(CDTC(LOCB),ANAME(1,11),NROW,NCOL,KK,IN,IOUT)
      CALL U2DREL(BOT(LOCB),ANAME(1,5),NROW,NCOL,KK,IN,IOUT)
C
C2E-----READ VERTICAL CONDUCTANCE IF NOT BOTTOM LAYER
  110 IF(K.EQ.NLAY) GO TO 120
      CALL U2DREL(CV(LOC),ANAME(1,4),NROW,NCOL,KK,IN,IOUT)
C
C2F-----READ SECONDARY STORAGE CAPACITY IF TRANSIENT SIMULATION
C2F-----AND LAYER TYPE IS 2 OR 3
  120 IF(LAYCON(K).NE.3 .AND. LAYCON(K).NE.2) GO TO 200
      IF(ISS.EQ.0)CALL U2DREL(SC2(LOCT),ANAME(1,7),NROW,NCOL,KK,IN,IOUT)
C
C2G-----READ TOP ELEVATION(TOP) IF LAYER TYPE IS 2 OR 3
      CALL U2DREL(TOP(LOCT),ANAME(1,6),NROW,NCOL,KK,IN,IOUT)
  200 CONTINUE
C
C3------INITIALIZE AND CHECK GFD DATA
      CALL SGFD1N(HNEW,IBOUND,CR,CC,CV,CDTR,CDTC,
     1            NCOL,NROW,NLAY,IOUT)
C
C4------RETURN
      RETURN
      END
```

List of Variables for Module GFD1RP

Variable	Range	Definition
ANAME	Module	DIMENSION (6,11), Labels for printout of input arrays.
BOT	Package	DIMENSION (NODES), Elevation of the aquifer bottom. Although BOT is dimensioned to the size of the grid, space exists only for cells for which saturated thickness is calculated.
CC	Global	DIMENSION (NODES), Conductance in the column direction.
CDTC	Package	DIMENSION (NODES), Conductance divided by thickness in the column direction. Although CDTC is dimensioned to the size of the grid, space exists only for cells for which saturated thickness is calculated.
CDTR	Package	DIMENSION (NODES), Conductance divided by thickness in the row direction. Although CDTR is dimensioned to the size of the grid, space exists only for cells for which saturated thickness is calculated.
CR	Global	DIMENSION (NODES), Conductance in the row direction.
CV	Global	DIMENSION (NODES), Conductance in the vertical direction.
DELC	Global	DIMENSION (NROW), Cell dimension in the column direction. DELC(I) contains the width of row I.
DELR	Global	DIMENSION (NCOL), Cell dimension in the row direction. DELR(J) contains the width of column J.
HNEW	Global	DIMENSION (NODES), Most recent estimate of head in each cell.
IBOUND	Global	DIMENSION (NODES), Status of each cell: < 0, constant-head cell = 0, no-flow cell > 0, variable-head cell
IN	Package	Primary unit number from which input for this package will be read.
IOUT	Global	Primary unit number for all printed output.
ISS	Package	Steady-state flag. = 0, simulation is transient not 0, simulation is steady state.
K	Module	Index for layers.
KB	Module	Index for layer within BOT, CDTR, and CDTC arrays.
KK	Module	Temporary variable set equal to K. KK is used as an actual argument in subroutine calls to avoid using the DO loop variable K as an argument, which causes problems with some compilers.
KT	Module	Index for layer within TOP and (if transient) SC2 arrays.
LAYCON	Package	DIMENSION (80) Layer-type code: 0 -- Layer is strictly confined. 1 -- Layer is strictly unconfined. 2 -- Layer is convertible between confined and unconfined (transmissivity is constant). 3 -- Layer is convertible between confined and unconfined (transmissivity varies).
LOC	Module	Pointer used to point to different layers in conductance arrays.
LOCB	Module	Pointer used to point to different layers in BOT, CDTR, and CDTC arrays.
LOCT	Module	Pointer used to point to different layers in TOP and SC2 arrays.
NCOL	Global	Number of columns in the grid.
NIJ	Module	Number of cells in a layer.
NLAY	Global	Number of layers in the grid.

```
NODES    Global    Number of cells (nodes) in the finite-difference grid.
NROW     Global    Number of rows in the grid.
SC1      Package   DIMENSION (NODES), Primary storage capacity.
SC2      Package   DIMENSION (NODES), Secondary storage capacity.
                   Although SC2 is dimensioned to the size of the grid,
                   space exists only for cells that can convert between
                   confined and unconfined.
TOP      Package   DIMENSION (NODES), Elevation of the aquifer top.
                   Although TOP is dimensioned to the size of the grid,
                   space exists only for cells that can convert between
                   confined and unconfined.
```

```
                            GFD1FM Module
                            -------------


            SUBROUTINE GFD1FM(HCOF,RHS,HOLD,SC1,HNEW,IBOUND,CR,CC,CV,
           1                  CDTR,CDTC,BOT,TOP,SC2,DELT,ISS,KITER,KSTP,KPER,
           2                  NCOL,NROW,NLAY,IOUT)
C-----VERSION 0912 19SEP1989 GFD1FM
C
C        *****************************************************************
C        ADD LEAKAGE CORRECTION AND STORAGE TO HCOF AND RHS,  AND CALCULATE
C        CONDUCTANCE AS REQUIRED
C        *****************************************************************
C
C           SPECIFICATIONS:
C        -----------------------------------------------------------------
         DOUBLE PRECISION HNEW
C
         DIMENSION HCOF(NCOL,NROW,NLAY),RHS(NCOL,NROW,NLAY),
        1    HOLD(NCOL,NROW,NLAY),SC1(NCOL,NROW,NLAY),HNEW(NCOL,NROW,NLAY),
        2    IBOUND(NCOL,NROW,NLAY),CR(NCOL,NROW,NLAY),
        3    CC(NCOL,NROW,NLAY),CV(NCOL,NROW,NLAY),CDTR(NCOL,NROW,NLAY),
        4    CDTC(NCOL,NROW,NLAY),BOT(NCOL,NROW,NLAY),TOP(NCOL,NROW,NLAY),
        5    SC2(NCOL,NROW,NLAY)
C
         COMMON /FLWCOM/LAYCON(80)
C        -----------------------------------------------------------------
         KB=0
         KT=0
C
C1------FOR EACH LAYER: IF T VARIES CALCULATE HORIZONTAL CONDUCTANCES
         DO 100 K=1,NLAY
         KK=K
         IF(LAYCON(K).EQ.3 .OR. LAYCON(K).EQ.2) KT=KT+1
C
C1A-----IF LAYER TYPE IS NOT 1 OR 3 THEN SKIP THIS LAYER.
         IF(LAYCON(K).NE.3 .AND. LAYCON(K).NE.1) GO TO 100
         KB=KB+1
C
C1B-----FOR LAYER TYPES 1 & 3 CALL SGFDC1 TO CALCULATE
C1B-----HORIZONTAL CONDUCTANCES.
         CALL SGFD1H(HNEW,IBOUND,CR,CC,CV,CDTR,CDTC,BOT,TOP,
        1          KK,KB,KT,KITER,KSTP,KPER,NCOL,NROW,NLAY,IOUT)
   100 CONTINUE
C
C2------IF THE SIMULATION IS TRANSIENT ADD STORAGE TO HCOF AND RHS
         IF(ISS.NE.0) GO TO 201
         TLED=1./DELT
         KT=0
         DO 200 K=1,NLAY
C
C3------SEE IF THIS LAYER IS CONVERTIBLE OR NON-CONVERTIBLE.
         IF(LAYCON(K).EQ.3 .OR. LAYCON(K).EQ.2) GO TO 150
C4------NON-CONVERTIBLE LAYER, SO USE PRIMARY STORAGE
         DO 140 I=1,NROW
         DO 140 J=1,NCOL
         IF(IBOUND(J,I,K).LE.0) GO TO 140
         RHO=SC1(J,I,K)*TLED
         HCOF(J,I,K)=HCOF(J,I,K)-RHO
         RHS(J,I,K)=RHS(J,I,K)-RHO*HOLD(J,I,K)
   140 CONTINUE
         GO TO 200
```

```
C
C5------A CONVERTIBLE LAYER, SO CHECK OLD AND NEW HEADS TO DETERMINE
C5------WHEN TO USE PRIMARY AND SECONDARY STORAGE
  150 KT=KT+1
      DO 180 I=1,NROW
      DO 180 J=1,NCOL
C
C5A-----IF THE CELL IS EXTERNAL THEN SKIP IT.
      IF(IBOUND(J,I,K).LE.0) GO TO 180
      TP=TOP(J,I,KT)
      RHO2=SC2(J,I,KT)*TLED
      RHO1=SC1(J,I,K)*TLED
C
C5B-----FIND STORAGE FACTOR AT START OF TIME STEP.
      SOLD=RHO2
      IF(HOLD(J,I,K).GT.TP) SOLD=RHO1
C
C5C-----FIND STORAGE FACTOR AT END OF TIME STEP.
      HTMP=HNEW(J,I,K)
      SNEW=RHO2
      IF(HTMP.GT.TP) SNEW=RHO1
C
C5D-----ADD STORAGE TERMS TO RHS AND HCOF.
      HCOF(J,I,K)=HCOF(J,I,K)-SNEW
      RHS(J,I,K)=RHS(J,I,K) - SOLD*(HOLD(J,I,K)-TP) - SNEW*TP
C
  180 CONTINUE
C
  200 CONTINUE
C
C6------FOR EACH LAYER DETERMINE IF CORRECTION TERMS ARE NEEDED FOR
C6------FLOW DOWN INTO PARTIALLY SATURATED LAYERS.
  201 KT=0
      DO 300 K=1,NLAY
C
C7------SEE IF CORRECTION IS NEEDED FOR LEAKAGE FROM ABOVE.
      IF(LAYCON(K).NE.3 .AND. LAYCON(K).NE.2) GO TO 250
      KT=KT+1
      IF(K.EQ.1) GO TO 250
C
C7A-----FOR EACH CELL MAKE THE CORRECTION IF NEEDED.
      DO 220 I=1,NROW
      DO 220 J=1,NCOL
C
C7B-----IF THE CELL IS EXTERNAL(IBOUND<=0) THEN SKIP IT.
      IF(IBOUND(J,I,K).LE.0) GO TO 220
      HTMP=HNEW(J,I,K)
C
C7C-----IF HEAD IS ABOVE TOP THEN CORRECTION NOT NEEDED
      IF(HTMP.GE.TOP(J,I,KT)) GO TO 220
C
C7D-----WITH HEAD BELOW TOP ADD CORRECTION TERMS TO RHS AND HCOF.
      RHS(J,I,K)=RHS(J,I,K) + CV(J,I,K-1)*TOP(J,I,KT)
      HCOF(J,I,K)=HCOF(J,I,K) + CV(J,I,K-1)
  220 CONTINUE
C
```

```
C8------SEE IF THIS LAYER MAY NEED CORRECTION FOR LEAKAGE TO BELOW.
  250 IF(K.EQ.NLAY) GO TO 300
      IF(LAYCON(K+1).NE.3 .AND. LAYCON(K+1).NE.2) GO TO 300
      KTT=KT+1
C
C8A-----FOR EACH CELL MAKE THE CORRECTION IF NEEDED.
      DO 280 I=1,NROW
      DO 280 J=1,NCOL
C
C8B-----IF CELL IS EXTERNAL (IBOUND<=0) THEN SKIP IT.
      IF(IBOUND(J,I,K).LE.0) GO TO 280
C
C8C-----IF HEAD IN THE LOWER CELL IS LESS THAN TOP ADD CORRECTION
C8C-----TERM TO RHS.
      HTMP=HNEW(J,I,K+1)
      IF(HTMP.LT.TOP(J,I,KTT)) RHS(J,I,K)=RHS(J,I,K)
     1                            - CV(J,I,K)*(TOP(J,I,KTT)-HTMP)
  280 CONTINUE
  300 CONTINUE
C
C9------RETURN
      RETURN
      END
```

List of Variables for Module GFD1FM

Variable	Range	Definition
BOT	Package	DIMENSION (NCOL,NROW,NLAY), Elevation of the aquifer bottom. Although BOT is dimensioned to the size of the grid, space exists only for cells for which saturated thickness is calculated.
CC	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the column direction.
CDTC	Package	DIMENSION (NCOL,NROW,NLAY), Conductance divided by thickness in the column direction. Although CDTC is dimensioned to the size of the grid, space exists only for cells for which saturated thickness is calculated.
CDTR	Package	DIMENSION (NCOL,NROW,NLAY), Conductance divided by thickness in the row direction. Although CDTR is dimensioned to the size of the grid, space exists only for cells for which saturated thickness is calculated.
CR	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the row direction.
CV	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the vertical direction.
DELT	GLOBAL	Length of the current time step.
HCOF	Global	DIMENSION (NCOL,NROW,NLAY), Coefficient of head in the finite-difference equation.
HNEW	Global	DIMENSION (NCOL,NROW,NLAY), Most recent estimate of head in each cell.
HOLD	Global	DIMENSION (NCOL,NROW,NLAY), Head at the start of the current time step.
HTMP	Module	Temporary single precision equivalent of HNEW(J,I,K).
I	Module	Index for rows.
IBOUND	Global	DIMENSION (NCOL,NROW,NLAY), Status of each cell: < 0, constant-head cell $= 0$, no-flow cell > 0, variable-head cell
IOUT	Global	Primary unit number for all printed output.
ISS	Package	Steady-state flag. $= 0$, simulation is transient not 0, simulation is steady state.
J	Module	Index for columns.
K	Module	Index for layers.
KB	Module	Index for layer within BOT, CDTR, and CDTC arrays.
KITER	Global	Iteration counter. KITER=1 at the start of each time step.
KK	Module	Temporary variable set equal to K. KK is used as an actual argument in subroutine calls to avoid using the DO loop variable K as an argument, which causes problems with some compilers.
KPER	Global	Stress period counter.
KSTP	Global	Time step counter. KSTP=1 at the start of each stress period.
KT	Module	Index for layer within TOP and (if transient) SC2 arrays.
KTT	Module	Index to TOP array of layer immediately below layer K.
LAYCON	Package	DIMENSION (80) Layer-type code: 0 -- Layer is strictly confined. 1 -- Layer is strictly unconfined. 2 -- Layer is convertible between confined and unconfined (transmissivity is constant). 3 -- Layer is convertible between confined and unconfined (transmissivity varies).

NCOL	Global	Number of columns in the grid.
NLAY	Global	Number of layers in the grid.
NROW	Global	Number of rows in the grid.
RHO	Module	Storage capacity divided by time step length for strictly confined or strictly unconfined layers.
RHO1	Module	Confined storage capacity divided by time step length for convertible layers.
RHO2	Module	Unconfined storage capacity divided by time step length for convertible layers.
RHS	Global	DIMENSION (NCOL,NROW,NLAY), Right-hand side of finite-difference equation.
SC1	Package	DIMENSION (NCOL,NROW,NLAY), Primary storage capacity.
SC2	Package	DIMENSION (NCOL,NROW,NLAY), Secondary storage capacity. Although SC2 is dimensioned to the size of the grid, space exists only for cells that can convert between confined and unconfined.
SNEW	Module	Storage capacity divided by time step length at the end of the time step for convertible layers.
SOLD	Module	Storage capacity divided by time step length at the start of the time step for convertible layers.
TLED	Module	1/DELT.
TOP	Package	DIMENSION (NCOL,NROW,NLAY), Elevation of the aquifer top. Although TOP is dimensioned to the size of the grid, space exists only for cells that can convert between confined and unconfined.
TP	Module	Temporary equivalent of TOP(J,I,KT).

GFD1BD Module

```
      SUBROUTINE GFD1BD(VBNM,VBVL,MSUM,HNEW,IBOUND,HOLD,SC1,CR,CC,CV,
     1    TOP,SC2,DELT,ISS,NCOL,NROW,NLAY,KSTP,KPER,IGFDCB,
     2    ICBCFL,BUFF,IOUT)
C-----VERSION 1346 19SEP1989 GFD1BD
C
C     ******************************************************************
C     COMPUTE BUDGET FLOW TERMS FOR GFD -- STORAGE, CONSTANT HEAD, AND
C     FLOW ACROSS CELL WALLS
C     ******************************************************************
C
C     SPECIFICATIONS:
C     ------------------------------------------------------------------
      CHARACTER*4 VBNM,TEXT
      DOUBLE PRECISION HNEW
C
      DIMENSION HNEW(NCOL,NROW,NLAY),  IBOUND(NCOL,NROW,NLAY),
     1    HOLD(NCOL,NROW,NLAY),  SC1(NCOL,NROW,NLAY),
     2    CR(NCOL,NROW,NLAY),  CC(NCOL,NROW,NLAY),
     3    CV(NCOL,NROW,NLAY),  VBNM(4,20),  VBVL(4,20),
     4    SC2(NCOL,NROW,NLAY),
     5    TOP(NCOL,NROW,NLAY),BUFF(NCOL,NROW,NLAY)
C
      COMMON /FLWCOM/LAYCON(80)
C
      DIMENSION TEXT(4)
C
      DATA TEXT(1),TEXT(2),TEXT(3),TEXT(4) /'    ','    ',' STO','RAGE'/
C     ------------------------------------------------------------------
C
C1------INITIALIZE BUDGET ACCUMULATORS
      STOIN=0.
      STOUT=0.
C
C2------IF CELL-BY-CELL FLOWS ARE NEEDED THEN SET FLAG IBD.
      IBD=0
      IF(ICBCFL.NE.0 .AND. IGFDCB.GT.0) IBD=1
C
C3------IF STEADY STATE THEN SKIP ALL STORAGE CALCULATIONS
      IF(ISS.NE.0) GO TO 305
C
C4------IF CELL-BY-CELL FLOWS ARE NEEDED (IBD IS SET) CLEAR BUFFER
      IF(IBD.EQ.0) GO TO 220
      DO 210 K=1,NLAY
      DO 210 I=1,NROW
      DO 210 J=1,NCOL
      BUFF(J,I,K)=0.
  210 CONTINUE
C
C5------RUN THROUGH EVERY CELL IN THE GRID
  220 KT=0
      DO 300 K=1,NLAY
      LC=LAYCON(K)
      IF(LC.EQ.3 .OR. LC.EQ.2) KT=KT+1
      DO 300 I=1,NROW
      DO 300 J=1,NCOL
C
```

```
C6------CALCULATE FLOW FROM STORAGE (VARIABLE HEAD CELLS ONLY)
      IF(IBOUND(J,I,K).LE.0) GO TO 300
      HSING=HNEW(J,I,K)
C
C6A----CHECK LAYER TYPE TO SEE IF ONE STORAGE FACTOR OR TWO
      IF(LC.NE.3 .AND. LC.NE.2) GO TO 285
C
C6B----TWO STORAGE CAPACITIES
      TP=TOP(J,I,KT)
      SYA=SC2(J,I,KT)
      SCFA=SC1(J,I,K)
      SOLD=SYA
      IF(HOLD(J,I,K).GT.TP) SOLD=SCFA
      SNEW=SYA
      IF(HSING.GT.TP) SNEW=SCFA
      STRG=SOLD*(HOLD(J,I,K)-TP) + SNEW*TP - SNEW*HSING
      GO TO 288
C
C6C----ONE STORAGE CAPACITY
  285 SC=SC1(J,I,K)
      STRG=SC*HOLD(J,I,K) - SC*HSING
C
C7-----STORE CELL-BY-CELL FLOW IN BUFFER AND ADD TO ACCUMULATORS
  288 IF(IBD.EQ.1) BUFF(J,I,K)=STRG/DELT
      IF(STRG) 292,300,294
  292 STOUT=STOUT-STRG
      GO TO 300
  294 STOIN=STOIN+STRG
C
  300 CONTINUE
C
C8-----IF IBD FLAG IS SET RECORD THE CONTENTS OF THE BUFFER
      IF(IBD.EQ.1) CALL UBUDSV(KSTP,KPER,TEXT,
     1                          IGFDCB,BUFF,NCOL,NROW,NLAY,IOUT)
C
C9------ADD TOTAL RATES AND VOLUMES TO VBVL & PUT TITLES IN VBNM
  305 VBVL(1,MSUM)=VBVL(1,MSUM)+STOIN
      VBVL(2,MSUM)=VBVL(2,MSUM)+STOUT
      VBVL(3,MSUM)=STOIN/DELT
      VBVL(4,MSUM)=STOUT/DELT
      VBNM(1,MSUM)=TEXT(1)
      VBNM(2,MSUM)=TEXT(2)
      VBNM(3,MSUM)=TEXT(3)
      VBNM(4,MSUM)=TEXT(4)
      MSUM=MSUM+1
C
C10-----CALCULATE FLOW FROM CONSTANT HEAD NODES
      CALL SGFD1F(VBNM,VBVL,MSUM,HNEW,IBOUND,CR,CC,CV,TOP,DELT,
     1            NCOL,NROW,NLAY,KSTP,KPER,IBD,IGFDCB,ICBCFL,BUFF,IOUT)
C
C11-----CALCULATE AND SAVE FLOW ACROSS CELL BOUNDARIES IF C-B-C
C11-----FLOW TERMS ARE REQUESTED.
      IF(IBD.NE.0) CALL SGFD1B(HNEW,IBOUND,CR,CC,CV,TOP,NCOL,NROW,NLAY,
     1            KSTP,KPER,IGFDCB,BUFF,IOUT)
C
C12----RETURN
      RETURN
      END
```

Variable	Range	Definition
BUFF	Global	DIMENSION (NCOL,NROW,NLAY), Buffer used to accumulate information before printing or recording it.
CC	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the column direction
CR	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the row direction.
CV	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the vertical direction.
DELT	GLOBAL	Length of the current time step.
HNEW	Global	DIMENSION (NCOL,NROW,NLAY), Most recent estimate of head in each cell.
HOLD	Global	DIMENSION (NCOL,NROW,NLAY), Head at the start of the current time step.
HSING	Module	Temporary single precision equivalent of HNEW(J,I,K).
I	Module	Index for rows.
IBD	Package	Flag.
		= 0, cell-by-cell flow terms for this package will not be recorded this time step.
		= 1, cell-by-cell flow terms for this package will be recorded this time step.
IBOUND	Global	DIMENSION (NCOL,NROW,NLAY), Status of each cell:
		< 0, constant-head cell
		= 0, no-flow cell
		> 0, variable-head cell
ICBCFL	Global	Flag.
		= 0, cell-by-cell flow terms will not be recorded or printed this time step.
		not 0, cell-by-cell flow terms for this time step will be either printed (flow to constant-head cells) or recorded (all GFD terms) depending on IGFDCB.
IGFDCB	Package	Flag and a unit number.
		> 0, unit number on which the cell-by-cell flow terms will be recorded when ICBCFL is set.
		= 0, cell-by-cell flow terms for GFD will not be printed or recorded.
		< 0, flow from individual constant-head cells will be printed when ICBCFL is set.
IOUT	Global	Primary unit number for all printed output.
ISS	Package	Steady-state flag.
		= 0, simulation is transient
		not 0, simulation is steady state.
J	Module	Index for columns.
K	Module	Index for layers.
KPER	Global	Stress period counter.
KSTP	Global	Time step counter. KSTP=1 at the start of each stress period.
KT	Module	Index for layer within TOP and (if transient) SC2 arrays.
LAYCON	Package	DIMENSION (80) Layer-type code:
		0 -- Layer is strictly confined.
		1 -- Layer is strictly unconfined.
		2 -- Layer is convertible between confined and unconfined (transmissivity is constant).
		3 -- Layer is convertible between confined and unconfined (transmissivity varies).
LC	Module	Temporary equivalent of LAYCON(K).

MSUM	Global	Index for budget entries in VBVL and VBNM.
NCOL	Global	Number of columns in the grid.
NLAY	Global	Number of layers in the grid.
NROW	Global	Number of rows in the grid.
SC	Module	Temporary equivalent of SC1(J,I,K).
SC1	Package	DIMENSION (NCOL,NROW,NLAY), Primary storage capacity.
SC2	Package	DIMENSION (NCOL,NROW,NLAY), Secondary storage capacity. Although SC2 is dimensioned to the size of the grid, space exists only for cells that can convert between confined and unconfined.
SCFA	Module	Temporary equivalent of SC1(J,I,K).
SNEW	Module	Storage capacity at the end of the time step.
SOLD	Module	Storage capacity at the start of the time step.
STOIN	Module	Sum of decreases in storage volume for individual cells.
STOUT	Module	Sum of increases in storage volume for individual cells.
STRG	Module	Volume into or out of storage for an individual cell.
SYA	Module	Temporary equivalent of SC2(J,I,K).
TEXT	Module	Label for storage term in volumetric budget.
TOP	Package	DIMENSION (NCOL,NROW,NLAY), Elevation of the aquifer top. Although TOP is dimensioned to the size of the grid, space exists only for cells that can convert between confined and unconfined.
TP	Module	Temporary equivalent of TOP(J,I,KT).
VBNM	Global	DIMENSION (4,20), Labels for terms in volumetric budget.
VBVL	Global	DIMENSION (4,20), Values for terms in volumetric budget. For term "N", the values are: (1,N), Flow rate into the model this time step. (2,N), Flow rate out of the model this time step. (3,N), Cumulative volume into the model. (4,N), Cumulative volume out of the model.

```
      SUBROUTINE SGFD1N(HNEW,IBOUND,CR,CC,CV,CDTR,CDTC,
     1            NCOL,NROW,NLAY,IOUT)
C
C-----VERSION 1438 19SEP1989 SGFD1N
C
C     ******************************************************************
C     INITIALIZE AND CHECK GFD DATA
C     ******************************************************************
C
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
C
      DOUBLE PRECISION HNEW,HCNV
C
      DIMENSION HNEW(NCOL,NROW,NLAY),IBOUND(NCOL,NROW,NLAY),
     1     CDTR(NCOL,NROW,NLAY),CR(NCOL,NROW,NLAY),
     2     CC(NCOL,NROW,NLAY),CV(NCOL,NROW,NLAY),
     3     CDTC(NCOL,NROW,NLAY)
C
      COMMON /FLWCOM/LAYCON(80)
C     ------------------------------------------------------------------
C
C1------IF IBOUND=0, SET CR=CC=CV=CDTR=CDTC=0.
      KB=0
      DO 30 K=1,NLAY
      IF(LAYCON(K).EQ.3 .OR. LAYCON(K).EQ.1) KB=KB+1
      DO 30 I=1,NROW
      DO 30 J=1,NCOL
      IF(IBOUND(J,I,K).NE.0) GO TO 30
      IF(K.NE.NLAY) CV(J,I,K)=0.
      IF(K.NE.1) CV(J,I,K-1)=0.
      CC(J,I,K)=0.
      IF(I.NE.1) CC(J,I-1,K)=0.
      CR(J,I,K)=0.
      IF(J.NE.1) CR(J-1,I,K)=0.
      IF(LAYCON(K).NE.3 .AND. LAYCON(K).NE.1) GO TO 30
      CDTR(J,I,KB)=0.
      CDTC(J,I,KB)=0.
      IF(J.NE.1) CDTR(J-1,I,KB)=0.
      IF(I.NE.1) CDTC(J,I-1,KB)=0.
   30 CONTINUE
C
C2------CHECK IF ANY ACTIVE NODE WILL HAVE ALL ZERO CONDUCTANCE
C2------IF SO, CONVERT NODE TO NOFLOW
      HCNV=888.88
      KB=0
      DO 70 K=1,NLAY
      IF(LAYCON(K).EQ.1 .OR. LAYCON(K).EQ.3) GO TO 55
C2A-----WHEN LAYER TYPE 0 OR 2, CR, CC, OR CV MUST BE NONZERO
      DO 54 I=1,NROW
      DO 54 J=1,NCOL
      IF(IBOUND(J,I,K).EQ.0) GO TO 54
      IF(J.EQ.1) GO TO 41
      IF(CR(J-1,I,K).NE.0.) GO TO 54
   41 IF(J.EQ.NCOL) GO TO 43
      IF(CR(J,I,K).NE.0.) GO TO 54
```

```
      43 IF(I.EQ.1) GO TO 45
         IF(CC(J,I-1,K).NE.0.) GO TO 54
      45 IF(I.EQ.NROW) GO TO 47
         IF(CC(J,I,K).NE.0.) GO TO 54
      47 IF(K.EQ.NLAY) GO TO 51
         IF(CV(J,I,K).NE.0.) GO TO 54
      51 IF(K.EQ.1) GO TO 53
         IF(CV(J,I,K-1).NE.0.) GO TO 54
      53 IBOUND(J,I,K)=0
         HNEW(J,I,K)=HCNV
         WRITE(IOUT,52) K,I,J
      52 FORMAT(1X,'NODE (LAYER,ROW,COL)',3I4,
        1        ' ELIMINATED BECAUSE ALL CONDUCTANCES TO NODE ARE 0')
      54 CONTINUE
         GO TO 70
C
C2B-----WHEN LAYER TYPE IS 1 OR 3, CDTR, CDTC, OR CV MUST BE NONZERO
      55 KB=KB+1
         DO 69 I=1,NROW
         DO 69 J=1,NCOL
         IF(IBOUND(J,I,K).EQ.0) GO TO 69
         IF(K.EQ.NLAY) GO TO 56
         IF(CV(J,I,K).NE.0.) GO TO 69
      56 IF(K.EQ.1) GO TO 57
         IF(CV(J,I,K-1).NE.0.) GO TO 69
      57 IF(J.EQ.1) GO TO 59
         IF(CDTR(J-1,I,KB).NE.0.) GO TO 69
      59 IF(J.EQ.NCOL) GO TO 61
         IF(CDTR(J,I,KB).NE.0.) GO TO 69
      61 IF(I.EQ.1) GO TO 63
         IF(CDTC(J,I-1,KB).NE.0.) GO TO 69
      63 IF(I.EQ.NROW) GO TO 67
         IF(CDTC(J,I,KB).NE.0.) GO TO 69
      67 IBOUND(J,I,K)=0
         HNEW(J,I,K)=HCNV
         CC(J,I,K)=0.
         WRITE(IOUT,52) K,I,J
      69 CONTINUE
      70 CONTINUE
C
C6------RETURN
     100 RETURN
         END
```

List of Variables for Module SGFD1N

Variable	Range	Definition
CC	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the column direction.
CDTC	Package	DIMENSION (NCOL,NROW,NLAY), Conductance divided by thickness in the column direction. Although CDTC is dimensioned to the size of the grid, space exists only for cells for which saturated thickness is calculated.
CDTR	Package	DIMENSION (NCOL,NROW,NLAY), Conductance divided by thickness in the row direction. Although CDTR is dimensioned to the size of the grid, space exists only for cells for which saturated thickness is calculated.
CR	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the row direction.
CV	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the vertical direction.
HCNV	Module	Value of head used to indicate that a cell has been converted to no flow because all conductances to that cell are 0.
HNEW	Global	DIMENSION (NCOL,NROW,NLAY), Most recent estimate of head in each cell.
I	Module	Index for rows.
IBOUND	Global	DIMENSION (NCOL,NROW,NLAY), Status of each cell: < 0, constant-head cell $= 0$, no-flow cell > 0, variable-head cell
IOUT	Global	Primary unit number for all printed output.
J	Module	Index for columns.
K	Module	Index for layers.
KB	Module	Index for layer within CDTR and CDTC arrays.
LAYCON	Package	DIMENSION (80) Layer-type code: 0 -- Layer is strictly confined. 1 -- Layer is strictly unconfined. 2 -- Layer is convertible between confined and unconfined (transmissivity is constant). 3 -- Layer is convertible between confined and unconfined (transmissivity varies).
NCOL	Global	Number of columns in the grid.
NLAY	Global	Number of layers in the grid.
NROW	Global	Number of rows in the grid.

```
      SUBROUTINE SGFD1H(HNEW,IBOUND,CR,CC,CV,CDTR,CDTC,BOT,
     1          TOP,K,KB,KT,KITER,KSTP,KPER,NCOL,NROW,NLAY,IOUT)
C
C-----VERSION 1318 19SEP1989 SGFD1H
C
C     ***********************************************************************
C     COMPUTE CONDUCTANCE FROM SATURATED THICKNESS AND CONDUCTANCE
C     DIVIDED BY THICKNESS
C     ***********************************************************************
C
C     SPECIFICATIONS:
C     ----------------------------------------------------------------
      DOUBLE PRECISION HNEW
C
      DIMENSION HNEW(NCOL,NROW,NLAY),IBOUND(NCOL,NROW,NLAY),
     1      CR(NCOL,NROW,NLAY), CC(NCOL,NROW,NLAY), CV(NCOL,NROW,NLAY),
     2      CDTR(NCOL,NROW,NLAY), CDTC(NCOL,NROW,NLAY),
     3      BOT(NCOL,NROW,NLAY),TOP(NCOL,NROW,NLAY)
C
      COMMON /FLWCOM/LAYCON(80)
C     ----------------------------------------------------------------
C
C1------CALCULATE SATURATED THICKNESS AT EACH ACTIVE NODE AND STORE
C1------TEMPORARILY IN CC
      DO 200 I=1,NROW
      DO 200 J=1,NCOL
C
C1A-----IF CELL IS INACTIVE THEN SET THICKNESS = 0.
      IF(IBOUND(J,I,K).NE.0) GO TO 10
      CC(J,I,K)=0.
      GO TO 200
C
C1B-----CALCULATE SATURATED THICKNESS.
   10 HD=HNEW(J,I,K)
      IF(LAYCON(K).EQ.1) GO TO 50
      IF(HD.GT.TOP(J,I,KT)) HD=TOP(J,I,KT)
   50 THCK=HD-BOT(J,I,KB)
      IF(THCK.LE.0.) GO TO 100
C
C1C-----IF SATURATED THICKNESS>0 THEN SAVE IT IN CC
      CC(J,I,K)=THCK
      GO TO 200
C
C1D-----WHEN SATURATED THICKNESS < 0, PRINT A MESSAGE AND SET
C1D-----IBOUND, THICKNESS, AND VERTICAL CONDUCTANCE =0
  100 WRITE(IOUT,150) K,I,J,KITER,KSTP,KPER
  150 FORMAT(1H0,10('*'),'NODE',3I4,' (LAYER,ROW,COL) WENT DRY'
     1      ,' AT ITERATION =',I3,'  TIME STEP =',I3
     2      ,'  STRESS PERIOD =',I3)
      HNEW(J,I,K)=1.E30
      CC(J,I,K)=0.
      IBOUND(J,I,K)=0
      IF(K.LT.NLAY) CV(J,I,K)=0.
      IF(K.GT.1) CV(J,I,K-1)=0.
  200 CONTINUE
C
```

```
C2------COMPUTE HORIZONTAL BRANCH CONDUCTANCE FROM SATURATED
C2------THICKNESS AT NODES AND CDT BETWEEN NODES.
C2------FOR EACH CELL CALCULATE BRANCH CONDUCTANCE FROM THAT CELL
C2------TO THE ONE ON THE RIGHT AND THE ONE IN FRONT.
      DO 400 I=1,NROW
      DO 400 J=1,NCOL
      B1=CC(J,I,K)
C
C2A-----IF B1=0 THEN SET CONDUCTANCE EQUAL TO 0. GO ON TO NEXT CELL.
      IF(B1.NE.0.) GO TO 310
      CR(J,I,K)=0.
      GO TO 400
C
C2B-----IF THIS IS NOT THE LAST COLUMN(RIGHTMOST) THEN CALCULATE
C2B-----BRANCH CONDUCTANCE IN THE ROW DIRECTION (CR) TO THE RIGHT.
  310 IF(J.EQ.NCOL) GO TO 330
      B2=CC(J+1,I,K)
      RATIO=B2/B1
      IF(RATIO.NE.0.) GO TO 320
      CR(J,I,K)=0.
      GO TO 330
C
  320 THCK=(B1+B2)*.5
      IF(RATIO.GE.1.25 .OR. RATIO.LE.0.8) THCK=(B2-B1)/ALOG(RATIO)
      CR(J,I,K)=THCK*CDTR(J,I,KB)
C
C2C-----IF THIS IS NOT THE LAST ROW(FRONTMOST) THEN CALCULATE
C2C-----BRANCH CONDUCTANCE IN THE COLUMN DIRECTION (CC) TO THE FRONT.
  330 IF(I.EQ.NROW) GO TO 400
      B2=CC(J,I+1,K)
      RATIO=B2/B1
      IF(RATIO.NE.0.) GO TO 340
      CC(J,I,K)=0.
      GO TO 400
C
  340 THCK=(B1+B2)*.5
      IF(RATIO.GE.1.25 .OR. RATIO.LT.0.8) THCK=(B2-B1)/ALOG(RATIO)
      CC(J,I,K)=THCK*CDTC(J,I,KB)
  400 CONTINUE
C
C3------RETURN
      RETURN
      END
```

List of Variable for Module SGFD1H

Variable	Range	Definition
B1	Module	Saturated thickness at node (J,I,K).
B2	Module	Saturated thickness at node (J+1,I,K) or node (J,I+1,K).
BOT	Package	DIMENSION (NCOL,NROW,NLAY), Elevation of the aquifer bottom. Although BOT is dimensioned to the size of the grid, space exists only for cells for which saturated thickness is calculated.
CC	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the column direction. This array is also used to temporarily hold saturated thickness.
CDTC	Package	DIMENSION (NCOL,NROW,NLAY), Conductance divided by thickness in the column direction. Although CDTC is dimensioned to the size of the grid, space exists only for cells for which saturated thickness is calculated.
CDTR	Package	DIMENSION (NCOL,NROW,NLAY), Conductance divided by thickness in the row direction. Although CDTR is dimensioned to the size of the grid, space exists only for cells for which saturated thickness is calculated.
CR	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the row direction.
CV	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the vertical direction.
HD	Module	Single precision equivalent of HNEW(J,I,K).
HNEW	Global	DIMENSION (NCOL,NROW,NLAY), Most recent estimate of head in each cell.
I	Module	Index for rows.
IBOUND	Global	DIMENSION (NCOL,NROW,NLAY), Status of each cell: < 0, constant-head cell = 0, no-flow cell > 0, variable-head cell
IOUT	Global	Primary unit number for all printed output.
J	Module	Index for columns.
K	Module	Index for layers.
KB	Module	Index for layer within BOT, CDTR, and CDTC arrays.
KITER	Global	Iteration counter. KITER=1 at the start of each time step.
KPER	Global	Stress period counter.
KSTP	Global	Time step counter. KSTP=1 at the start of each stress period.
KT	Module	Index for layer within TOP array.
LAYCON	Package	DIMENSION (80) Layer-type code: 0 -- Layer is strictly confined. 1 -- Layer is strictly unconfined. 2 -- Layer is convertible between confined and unconfined (transmissivity is constant). 3 -- Layer is convertible between confined and unconfined (transmissivity varies).
NCOL	Global	Number of columns in the grid.
NLAY	Global	Number of layers in the grid.
NROW	Global	Number of rows in the grid.
RATIO	Module	B2/B1.
THCK	Module	Saturated thickness.
TOP	Package	DIMENSION (NCOL,NROW,NLAY), Elevation of the aquifer top. Although TOP is dimensioned to the size of the grid, space exists only for cells that can convert between confined and unconfined.

```
      SUBROUTINE SGFD1B(HNEW,IBOUND,CR,CC,CV,TOP,NCOL,NROW,NLAY,
     1       KSTP,KPER,IGFDCB,BUFF,IOUT)
C
C-----VERSION 1328 19SEP1989 SGFD1B
C
C     ******************************************************************
C     COMPUTE FLOW ACROSS EACH CELL WALL
C     ******************************************************************
C
C     SPECIFICATIONS:
C     ------------------------------------------------------------------
      CHARACTER*4 TEXT
      DOUBLE PRECISION HNEW,HD
C
      DIMENSION HNEW(NCOL,NROW,NLAY),  IBOUND(NCOL,NROW,NLAY),
     1     CR(NCOL,NROW,NLAY),  CC(NCOL,NROW,NLAY),
     2     CV(NCOL,NROW,NLAY),  TOP(NCOL,NROW,NLAY),
     3     BUFF(NCOL,NROW,NLAY)
C
      COMMON /FLWCOM/LAYCON(80)
C
      DIMENSION TEXT(12)
C
      DATA TEXT(1),TEXT(2),TEXT(3),TEXT(4),TEXT(5),TEXT(6),TEXT(7),
     1   TEXT(8),TEXT(9),TEXT(10),TEXT(11),TEXT(12)
     2   /'FLOW',' RIG','HT F','ACE ',
     2    'FLOW',' FRO','NT F','ACE ','FLOW',' LOW','ER F','ACE '/
C     ------------------------------------------------------------------
C
      NCM1=NCOL-1
      IF(NCM1.LT.1) GO TO 405
C
C1-----CLEAR THE BUFFER
      DO 310 K=1,NLAY
      DO 310 I=1,NROW
      DO 310 J=1,NCOL
      BUFF(J,I,K)=0.
  310 CONTINUE
C
C2-----FOR EACH CELL CALCULATE FLOW THRU RIGHT FACE & STORE IN BUFFER
      DO 400 K=1,NLAY
      DO 400 I=1,NROW
      DO 400 J=1,NCM1
      IF((IBOUND(J,I,K).LE.0) .AND. (IBOUND(J+1,I,K).LE.0)) GO TO 400
      HDIFF=HNEW(J,I,K)-HNEW(J+1,I,K)
      BUFF(J,I,K)=HDIFF*CR(J,I,K)
  400 CONTINUE
C
C3-----RECORD CONTENTS OF BUFFER
      CALL UBUDSV(KSTP,KPER,TEXT(1),IGFDCB,BUFF,NCOL,NROW,NLAY,IOUT)
C
C4-----CLEAR THE BUFFER
  405 NRM1=NROW-1
      IF(NRM1.LT.1) GO TO 505
      DO 410 K=1,NLAY
      DO 410 I=1,NROW
```

```
            DO 410 J=1,NCOL
            BUFF(J,I,K)=0.
   410 CONTINUE
C
C5-----FOR EACH CELL CALCULATE FLOW THRU FRONT FACE & STORE IN BUFFER
            DO 500 K=1,NLAY
            DO 500 I=1,NRM1
            DO 500 J=1,NCOL
            IF((IBOUND(J,I,K).LE.0) .AND. (IBOUND(J,I+1,K).LE.0)) GO TO 500
            HDIFF=HNEW(J,I,K)-HNEW(J,I+1,K)
            BUFF(J,I,K)=HDIFF*CC(J,I,K)
   500 CONTINUE
C
C6-----RECORD CONTENTS OF BUFFER.
            CALL UBUDSV(KSTP,KPER,TEXT(5),IGFDCB,BUFF,NCOL,NROW,NLAY,IOUT)
   505 NLM1=NLAY-1
            IF(NLM1.LT.1) GO TO 1000
C
C7-----CLEAR THE BUFFER
            DO 510 K=1,NLAY
            DO 510 I=1,NROW
            DO 510 J=1,NCOL
            BUFF(J,I,K)=0.
   510 CONTINUE
C
C8-----FOR EACH CELL CALCULATE FLOW THRU LOWER FACE & STORE IN BUFFER
            KT=0
            DO 600 K=1,NLM1
            IF(LAYCON(K).EQ.3 .OR. LAYCON(K).EQ.2) KT=KT+1
            DO 600 I=1,NROW
            DO 600 J=1,NCOL
            IF((IBOUND(J,I,K).LE.0) .AND. (IBOUND(J,I,K+1).LE.0)) GO TO 600
            HD=HNEW(J,I,K+1)
            IF(LAYCON(K+1).NE.3 .AND. LAYCON(K+1).NE.2) GO TO 580
            TMP=HD
            IF(TMP.LT.TOP(J,I,KT+1)) HD=TOP(J,I,KT+1)
   580 HDIFF=HNEW(J,I,K)-HD
            BUFF(J,I,K)=HDIFF*CV(J,I,K)
   600 CONTINUE
C
C9-----RECORD CONTENTS OF BUFFER.
            CALL UBUDSV(KSTP,KPER,TEXT(9),IGFDCB,BUFF,NCOL,NROW,NLAY,IOUT)
C
C10----RETURN
  1000 RETURN
            END
```

List of Variable for Module SGFD1B

Variable	Range	Definition
BUFF	Global	DIMENSION (NCOL,NROW,NLAY), Buffer used to accumulate information before printing or recording it.
CC	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the column direction.
CR	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the row direction.
CV	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the vertical direction.
HD	Module	Temporary equivalent of HNEW(J,I,K+1) or TOP(J,I,K+1).
HDIFF	Module	Head difference between two adjacent nodes.
HNEW	Global	DIMENSION (NCOL,NROW,NLAY), Most recent estimate of head in each cell.
I	Module	Index for rows.

IBOUND	Global	DIMENSION (NCOL,NROW,NLAY), Status of each cell:
		    < 0, constant-head cell
		    = 0, no-flow cell
		    > 0, variable-head cell

IGFDCB	Package	Flag and a unit number.
		    > 0, unit number on which the cell-by-cell flow terms will be recorded when ICBCFL is set.
		    = 0, cell-by-cell flow terms for GFD will not be printed or recorded.
		    < 0, flow from individual constant-head cells will be printed when ICBCFL is set.

IOUT	Global	Primary unit number for all printed output.
J	Module	Index for columns.
K	Module	Index for layers.
KPER	Global	Stress period counter.
KSTP	Global	Time step counter. KSTP=1 at the start of each stress period.
KT	Module	Index for layer within TOP array.

LAYCON	Package	DIMENSION (80) Layer-type code:
		    0 -- Layer is strictly confined.
		    1 -- Layer is strictly unconfined.
		    2 -- Layer is convertible between confined and unconfined (transmissivity is constant).
		    3 -- Layer is convertible between confined and unconfined (transmissivity varies).

NCM1	Module	NCOL-1.
NCOL	Global	Number of columns in the grid.
NLAY	Global	Number of layers in the grid.
NLM1	Module	NLAY-1
NRM1	Module	NROW-1.
NROW	Global	Number of rows in the grid.
TEXT	Module	Labels for flow across cell walls in cell-by-cell budget file.
TMP	Module	Single precision equivalent of HD.
TOP	Package	DIMENSION (NCOL,NROW,NLAY), Elevation of the aquifer top. Although TOP is dimensioned to the size of the grid, space exists only for cells that can convert between confined and unconfined.

```
      SUBROUTINE SGFD1F(VBNM,VBVL,MSUM,HNEW,IBOUND,CR,CC,CV,
     1    TOP,DELT,NCOL,NROW,NLAY,KSTP,KPER,IBD,IGFDCB,ICBCFL,
     2    BUFF,IOUT)
C-----VERSION 1429 19SEP1989 SGFD1F
C
C     ****************************************************************
C     COMPUTE FLOW FROM CONSTANT HEAD NODES
C     ****************************************************************
C
C     SPECIFICATIONS:
C     ----------------------------------------------------------------
      CHARACTER*4 VBNM,TEXT
      DOUBLE PRECISION HNEW,HD
C
      DIMENSION HNEW(NCOL,NROW,NLAY), IBOUND(NCOL,NROW,NLAY),
     1      CR(NCOL,NROW,NLAY), CC(NCOL,NROW,NLAY),
     2      CV(NCOL,NROW,NLAY), VBNM(4,20), VBVL(4,20),
     3      TOP(NCOL,NROW,NLAY),BUFF(NCOL,NROW,NLAY)
C
      COMMON /FLWCOM/LAYCON(80)
C
      DIMENSION TEXT(4)
C
      DATA TEXT(1),TEXT(2),TEXT(3),TEXT(4) /'   C','ONST','ANT ','HEAD'/
C     ----------------------------------------------------------------
C
C1------CLEAR BUDGET ACCUMULATORS
      CHIN=0.
      CHOUT=0.
C
C2------CLEAR BUFFER IF CELL-BY-CELL FLOW TERM FLAG(IBD) IS SET
      IF(IBD.EQ.0) GO TO 8
      DO 5 K=1,NLAY
      DO 5 I=1,NROW
      DO 5 J=1,NCOL
      BUFF(J,I,K)=0.
    5 CONTINUE
C
C3------FOR EACH CELL IF IT IS CONSTANT HEAD COMPUTE FLOW ACROSS 6
C3-----FACES.
    8 KT=0
      DO 200 K=1,NLAY
      LC=LAYCON(K)
      IF(LC.EQ.3 .OR. LC.EQ.2) KT=KT+1
      DO 200 I=1,NROW
      DO 200 J=1,NCOL
C
C4-----IF CELL IS NOT CONSTANT HEAD SKIP IT & GO ON TO NEXT CELL.
      IF (IBOUND(J,I,K).GE.0)GO TO 200
C
C5-----CLEAR FIELDS FOR SIX FLOW RATES.
      X1=0.
      X2=0.
      X3=0.
      X4=0.
      X5=0.
      X6=0.
```

```
C6-----FOR EACH FACE OF THE CELL CALCULATE FLOW THROUGH THAT FACE
C6-----OUT OF THE CONSTANT HEAD CELL AND INTO THE FLOW DOMAIN.
C6-----COMMENTS 7-11 APPEAR ONLY IN THE SECTION HEADED BY COMMENT 6A
C6-----BUT THEY APPLY IN A SIMILAR MANNER TO THE SECTIONS HEADED
C6-----BY COMMENTS 6B-6F.
C
C6A----CALCULATE FLOW THROUGH THE LEFT FACE
C
C7-----IF THERE IS NOT A VARIABLE HEAD CELL ON THE OTHER SIDE OF THIS
C7-----FACE THEN GO ON TO THE NEXT FACE.
      IF(J.EQ.1) GO TO 30
      IF(IBOUND(J-1,I,K).LE.0)GO TO 30
      HDIFF=HNEW(J,I,K)-HNEW(J-1,I,K)
C
C8-----CALCULATE FLOW THROUGH THIS FACE INTO THE ADJACENT CELL.
      X1=HDIFF*CR(J-1,I,K)
C
C9-----TEST TO SEE IF FLOW IS POSITIVE OR NEGATIVE
      IF (X1) 10,30,20
C
C10----IF NEGATIVE ADD TO CHOUT(FLOW OUT OF DOMAIN TO CONSTANT HEAD).
   10 CHOUT=CHOUT-X1
      GO TO 30
C
C11----IF POSITIVE ADD TO CHIN(FLOW INTO DOMAIN FROM CONSTANT HEAD).
   20 CHIN=CHIN+X1
C
C6B----CALCULATE FLOW THROUGH THE RIGHT FACE
   30 IF(J.EQ.NCOL) GO TO 60
      IF(IBOUND(J+1,I,K).LE.0) GO TO 60
      HDIFF=HNEW(J,I,K)-HNEW(J+1,I,K)
      X2=HDIFF*CR(J,I,K)
      IF(X2)40,60,50
   40 CHOUT=CHOUT-X2
      GO TO 60
   50 CHIN=CHIN+X2
C
C6C----CALCULATE FLOW THROUGH THE BACK FACE.
   60 IF(I.EQ.1) GO TO 90
      IF (IBOUND(J,I-1,K).LE.0) GO TO 90
      HDIFF=HNEW(J,I,K)-HNEW(J,I-1,K)
      X3=HDIFF*CC(J,I-1,K)
      IF(X3) 70,90,80
   70 CHOUT=CHOUT-X3
      GO TO 90
   80 CHIN=CHIN+X3
C
C6D----CALCULATE FLOW THROUGH THE FRONT FACE.
   90 IF(I.EQ.NROW) GO TO 120
      IF(IBOUND(J,I+1,K).LE.0) GO TO 120
      HDIFF=HNEW(J,I,K)-HNEW(J,I+1,K)
      X4=HDIFF*CC(J,I,K)
      IF (X4) 100,120,110
  100 CHOUT=CHOUT-X4
      GO TO 120
  110 CHIN=CHIN+X4
C
```

```
C6E----CALCULATE FLOW THROUGH THE UPPER FACE
    120 IF(K.EQ.1) GO TO 150
        IF (IBOUND(J,I,K-1).LE.0) GO TO 150
        HD=HNEW(J,I,K)
        IF(LC.NE.3 .AND. LC.NE.2) GO TO 122
        TMP=HD
        IF(TMP.LT.TOP(J,I,KT)) HD=TOP(J,I,KT)
    122 HDIFF=HD-HNEW(J,I,K-1)
        X5=HDIFF*CV(J,I,K-1)
        IF(X5) 130,150,140
    130 CHOUT=CHOUT-X5
        GO TO 150
    140 CHIN=CHIN+X5
C
C6F----CALCULATE FLOW THROUGH THE LOWER FACE.
    150 IF(K.EQ.NLAY) GO TO 180
        IF(IBOUND(J,I,K+1).LE.0) GO TO 180
        HD=HNEW(J,I,K+1)
        IF(LAYCON(K+1).NE.3 .AND. LAYCON(K+1).NE.2) GO TO 152
        TMP=HD
        IF(TMP.LT.TOP(J,I,KT+1)) HD=TOP(J,I,KT+1)
    152 HDIFF=HNEW(J,I,K)-HD
        X6=HDIFF*CV(J,I,K)
        IF(X6) 160,180,170
    160 CHOUT=CHOUT-X6
        GO TO 180
    170 CHIN=CHIN+X6
C
C12-----SUM UP FLOWS THROUGH SIX SIDES OF CONSTANT HEAD CELL.
  180   RATE=X1+X2+X3+X4+X5+X6
C
C13-----PRINT THE INDIVIDUAL RATES IF REQUESTED(IGFDCB<0).
        IF(IGFDCB.LT.0.AND.ICBCFL.NE.0) WRITE(IOUT,900) (TEXT(N),N=1,4),
       1      KPER,KSTP,K,I,J,RATE
  900 FORMAT(1H0,4A4,'    PERIOD',I3,'   STEP',I3,'   LAYER',I3,
       1   '   ROW',I4,'   COL',I4,'   RATE ',G15.7)
C
C14----IF CELL-BY-CELL FLAG SET STORE SUM OF FLOWS FOR CELL IN BUFFER
        IF(IBD.EQ.1) BUFF(J,I,K)=RATE
C
  200 CONTINUE
C
C15----IF CELL-BY-CELL FLAG SET THEN RECORD CONTENTS OF BUFFER
        IF(IBD.EQ.1) CALL UBUDSV(KSTP,KPER,TEXT(1),
       1                    IGFDCB,BUFF,NCOL,NROW,NLAY,IOUT)
C
C
C16----SAVE TOTAL CONSTANT HEAD FLOWS AND VOLUMES IN VBVL TABLE
C16----FOR INCLUSION IN BUDGET. PUT LABELS IN VBNM TABLE.
        VBVL(1,MSUM)=VBVL(1,MSUM)+CHIN*DELT
        VBVL(2,MSUM)=VBVL(2,MSUM)+CHOUT*DELT
        VBVL(3,MSUM)=CHIN
        VBVL(4,MSUM)=CHOUT
C
C       ---SETUP VOLUMETRIC BUDGET NAMES
        VBNM(1,MSUM)=TEXT(1)
        VBNM(2,MSUM)=TEXT(2)
        VBNM(3,MSUM)=TEXT(3)
        VBNM(4,MSUM)=TEXT(4)
```

```
C
      MSUM=MSUM+1
C
C
C17----RETURN
      RETURN
      END
```

List of Variables for Module SGFD1F

Variable	Range	Definition
BUFF	Global	DIMENSION (NCOL,NROW,NLAY), Buffer used to accumulate information before printing or recording it.
CC	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the column direction.
CHIN	Module	Accumulator for flow into the model from constant-head cells.
CHOUT	Module	Accumulator for flow out of the model to constant-head cells.
CR	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the row direction.
CV	Global	DIMENSION (NCOL,NROW,NLAY), Conductance in the vertical direction.
DELT	GLOBAL	Length of the current time step.
HD	Module	Temporary equivalent for HNEW(J,I,K+1) or TOP(J,I,K+1).
HDIFF	Module	Head difference between two adjacent nodes.
HNEW	Global	DIMENSION (NCOL,NROW,NLAY), Most recent estimate of head in each cell.
I	Module	Index for rows.
IBD	Package	Flag. = 0, cell-by-cell flow terms for this package will not be recorded this time step. = 1, cell-by-cell flow terms for this package will be recorded this time step.
IBOUND	Global	DIMENSION (NCOL,NROW,NLAY), Status of each cell: < 0, constant-head cell = 0, no-flow cell > 0, variable-head cell
ICBCFL	Global	Flag. = 0, cell-by-cell flow terms will not be recorded or printed this time step. not 0, cell-by-cell flow terms for this time step will be either printed (flow to constant-head cells) or recorded (all GFD terms) depending on IGFDCB.
IGFDCB	Package	Flag and a unit number. > 0, unit number on which the cell-by-cell flow terms will be recorded when ICBCFL is set. = 0, cell-by-cell flow terms for GFD will not be printed or recorded. < 0, flow from individual constant-head cells will be printed when ICBCFL is set.
IOUT	Global	Primary unit number for all printed output.
J	Module	Index for columns.
K	Module	Index for layers.
KPER	Global	Stress period counter.
KSTP	Global	Time step counter. KSTP=1 at the start of each stress period.
KT	Module	Index for layer within TOP array.
LAYCON	Package	DIMENSION (80) Layer-type code: 0 -- Layer is strictly confined. 1 -- Layer is strictly unconfined. 2 -- Layer is convertible between confined and unconfined (transmissivity is constant). 3 -- Layer is convertible between confined and unconfined (transmissivity varies).
LC	Module	Temporary equivalent of LAYCON(K).

MSUM	Global	Index for budget entries in VBVL and VBNM.
N	Module	Index for TEXT when printing cell-by-cell constant-head flow.
NCOL	Global	Number of columns in the grid.
NLAY	Global	Number of layers in the grid.
NROW	Global	Number of rows in the grid.
RATE	Module	Flow from a constant-head cell into the model.
TEXT	Module	Label for constant-head flow in volumetric budget.
TMP	Module	Single precision equivalent of HD.
TOP	Package	DIMENSION (NCOL,NROW,NLAY), Elevation of the aquifer top. Although TOP is dimensioned to the size of the grid, space exists only for cells that can convert between confined and unconfined.
VBNM	Global	DIMENSION (4,20), Labels for terms in volumetric budget.
VBVL	Global	DIMENSION (4,20), Values for terms in volumetric budget. For term "N", the values are:
		$\quad$(1,N), Flow rate into the model this time step.
		$\quad$(2,N), Flow rate out of the model this time step.
		$\quad$(3,N), Cumulative volume into the model.
		$\quad$(4,N), Cumulative volume out of the model.
X1	Module	Flow through the left face.
X2	Module	Flow through the right face.
X3	Module	Flow through the back face.
X4	Module	Flow through the front face.
X5	Module	Flow through the upper face.
X6	Module	Flow through the lower face.

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